



FIRST LESSONS  
IN THE  
SCIENTIFIC PRINCIPLES  
OF AGRICULTURE.  
FOR SCHOOLS  
AND  
PRIVATE INSTRUCTION.

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BY SIR WM. DAWSON, C.M.G., LL.D., F.R.S.  
LATE PRINCIPAL OF M'GILL UNIVERSITY.

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**S. P. ROBINS, LL.D.,**  
PRINCIPAL OF THE M'GILL NORMAL SCHOOL.

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\* For these chapters and sections the editor must be held responsible.

† This chapter and these sections have been much modified by the editor.



# PREFACE.

FIRST EDITION.

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The writer of this little book had, in his youth, some opportunities of becoming familiar with agricultural operations; and read with eagerness and enthusiasm those remarkable works of Liebig and Johnston, which in 1840 and the following years revived throughout Britain and America the interest in the applications of chemistry to agriculture which had been awakened by Sir Humphrey Davy. It was subsequently his duty, as Superintendent of Education in Nova Scotia, to make an effort to introduce the teaching of agricultural chemistry into the schools of that Province; and more recently it has fallen to him to communicate some knowledge of the subject to the teachers in training in the McGill Normal School in Montreal.

From these labors has grown the present work, which is intended as a text-book for teachers desirous of introducing the study of Scientific Agriculture into their schools, and also as a manual for young men who may be pursuing the subject as a branch of private study. It is designed to place before such persons the facts and principles which the experience of the writer has shown to be most important in relation to the existing state of agriculture in British America.

The writer has ventured to deviate from the plan of ordinary school text-books, and to throw the matter into the form of a series of reading lessons adapted to the use of a senior class. It is proposed that the pupils shall, either in school or at home, read a few pages daily, or as often as may be convenient, and shall then answer questions thereon, and receive such further information as the teacher may be able to give. In this way any intelligent pupil may so master the elements of the subject as to be able to reduce its principles to practice in farming operations, and to enter with advantage on the study of larger works.

It is to be observed that this work is strictly elementary. It makes no pretension to completeness, either in chemical science or practical agriculture. It is not intended to finish the studies of the pupil on this subject, but to render them more easy and profitable; and the writer would advise both the teacher and the practical farmer desirous of obtaining a more full acquaintance with the subject, to add to their libraries as many as possible of the larger agricultural books, of which so many are now accessible.

The writer acknowledges with thanks his obligations to Dr. T. STERRY HUNT, Professor of Applied Chemistry in McGill University, and to PROF. ROBINS, of the McGill Normal School, for many valuable suggestions and corrections.

McGill College, 2nd January, 1864.



## Preface to the New Edition.

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Thirty years ago the little work of which this recension is offered to schools, especially to the schools of the Province of Quebec, was an admirable, succinct presentation of those parts of agricultural science of which it treated, as then understood. Since that time chemical science has undergone a remarkable development, and within a very few years agricultural science has been profoundly modified by the discovery of new relations of nitrogen to the soil and, in consequence, of the soil to plant life. To maintain the usefulness of the book by bringing it up to date, it has been necessary to make some alterations and many additions. As it would be unfair to hold the eminent author responsible for these, it might, perhaps, have been better by the use of parentheses or of different type to have kept distinct the changes made by the editor. But it was found that such an arrangement would interfere with the usefulness of the book in the hands of elementary pupils, and no such typographical distinctions have been made. It must suffice to say that, besides the accommodation of chemical terminology and formulæ to modern usage, the editor is responsible for those chapters and sections of chapters which in the table of contents are marked with asterisks, for the experiments which are suggested and for the arithmetical exercises which constitute an important feature of the book.



If it should appear desirable, the editor will provide simple apparatus and a supply of chemicals for the performance of the experiments referred to in the text, on being authorized so to do by the Protestant Committee of the Council of Public Instruction, under whose authority this little book is issued.

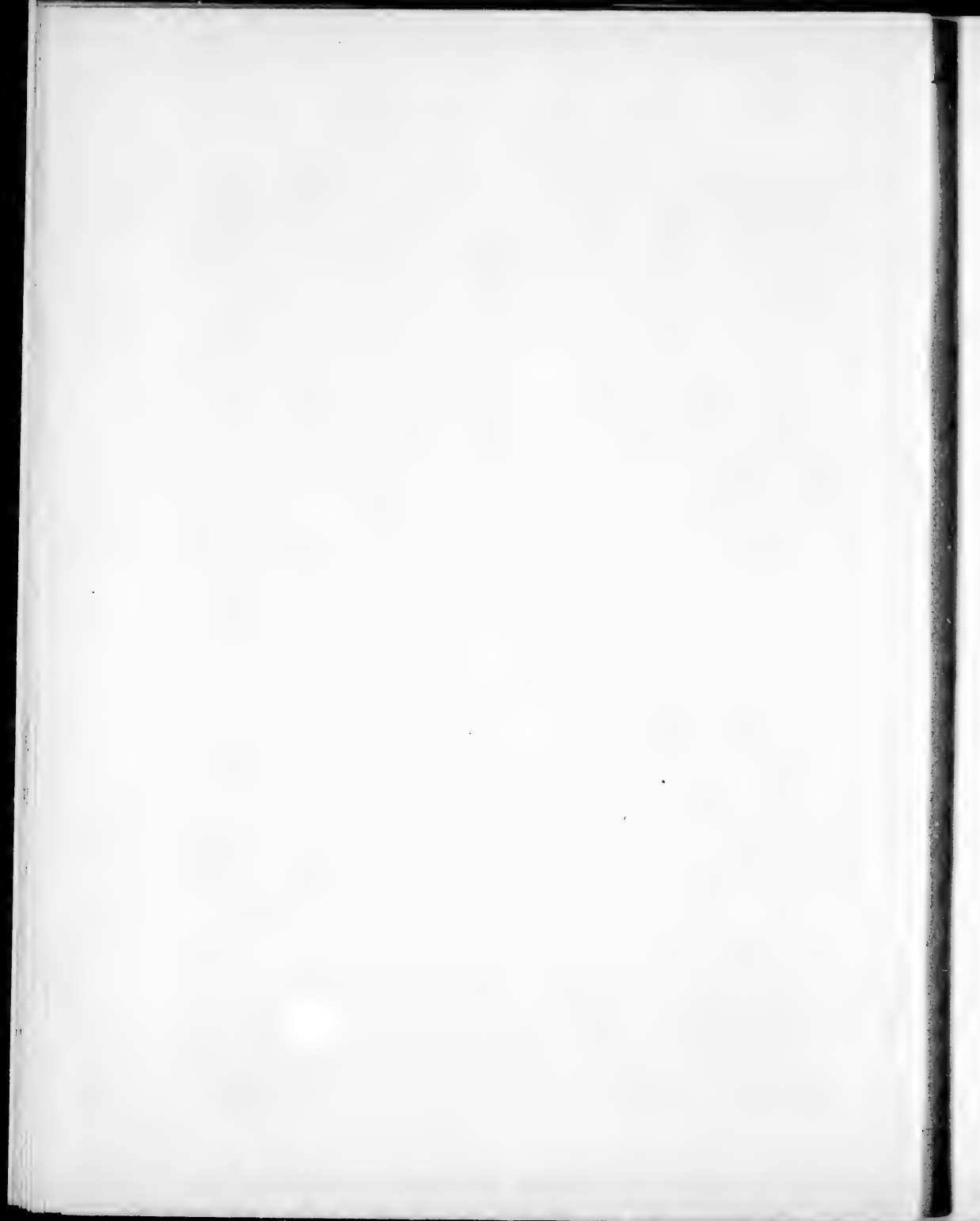
Practical teachers will at once recognize the value of the arithmetical exercises which are provided. They will furnish profitable employment for pupils in the intervals of actual instruction by the teacher; they will serve to test the accuracy of each pupil's conception of the ideas presented; and they will firmly fasten on the mind the truths taught. Exact calculation is incompatible with vague, ill-defined notions of things.

Some of the arithmetical exercises are open to this criticism:—farm practice, the use of machinery, the value of land, the cost of labour, the price of artificial manure, and many other data of the problems presented differ, sometimes widely, in different localities; hence the data of many problems respecting the cost of raising crops will be more or less unsuitable to the district in which the school using the book is situated. Let teachers or pupils supply more appropriate data in additional problems of similar character. A discussion of differences will add interest to the work, and enhance the value of the instruction given. The methods of procedure will be similar although the data and the results will differ. The main thing is to teach the young generation of farmers to calculate, and to calculate in view of all the elements of the calculation. The editor believes that no young person can work out the examples in this book, and when he becomes a farmer, fail, as the pioneers of our country

failed, to remember that with every bushel of grain, with every ton of hay, he sells a part, a valuable part, indeed an indispensable part of his farm, a part that must be replaced by purchase from outside, if the fertility of the soil is to be maintained. In the examples furnished attention is directed to three substances only—nitrogen, phosphorus and potassium—because these are of the highest practical importance. It begins to be evident that by judicious treatment of the soil, by a wise rotation of crops, by carrying a sufficient amount of live stock, and by a painstaking husbanding of manures, the farm may be made to manufacture its own nitrogenous manures, and make good from its own resources the nitrogen sold in crops removed from the soil, although average Canadian farming fails to do this; but it is certain that every pound of phosphates and of potash sold must be brought back again from outside sources of supply, or the farm will surely deteriorate, and this the faster, the larger the immediate returns. It is hoped that the numerical examples will receive due attention in the schools, and will prove of great value in the instruction of young farmers.

Let nothing stated in this book be taken for granted, if in any way it can be brought to the test of actual experiment or calculation. In some respects it is better for a pupil to err as the result of his own inquiry, than to be right by a blind, uncritical reception of the conclusions of others. Properly used this book, while it would be absurd to suppose that it can teach practical farming, will help to raise up a generation of farmers accustomed to observe nature, to experiment, to think, to calculate, to trust themselves and to be successful.

S. P. R.



# FIRST LESSONS IN Scientific Agriculture.

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## INTRODUCTORY CHAPTER.

### THE SCIENCE OF AGRICULTURE.

#### § 1. *T'* relations of Theory and Practice.

In our time all useful arts are more or less closely connected with scientific facts and principles, and it is to this connection that these arts mainly owe their present high perfection and progressive improvement. The votary of abstract science may in his researches regard only the laws of nature, without reference to the arts of life; yet his discoveries necessarily bear on those arts, since the laws of nature are those under which the artisan or the farmer must work. They surround him on every side. They have fixed the properties of all the things he uses for his purposes, and have determined the steps of every process which can be successful.

It is the business of physical science carefully to explore nature, to ascertain the properties of every object, the laws which regulate every change and process, the conditions, in short, of existence and of

action which the Creator has imposed on the things which He has made. Such knowledge must be eminently practical ; it is truly power, inasmuch as it brings to bear upon matter that which is the grand agent of our mastery over it—enlightened thought. All the great forces of nature—heat, electricity, light, the various laws and properties of solids, of liquids, and of gases, and of the different kinds of matter—have been searched out by scientific investigation, and broken in and harnessed for the use of the practical man ; and every day new uses of substances, improvements of processes, adaptations of machines, are being carried out ; while every new fact or principle utilized brings in its train the uses of others.

Much popular misconception exists as to the relation of theory to practice in the industrial arts. There is a tendency to decry theory, as if it were mere speculation, while, on the other hand, the more learned sometimes sneer at mere practical skill, as if it were wholly empirical and destitute of any sound reason. The truth lies between these extremes, and may be illustrated by a familiar example from another art. A practical seaman must be able to perform all the active duties required of him in the ship—to steer, to go aloft, to reef sails ; and a mere landsman may be quite helpless in these matters, however much he may know of the theory of navigation. But the ship may be well manned with able-bodied and skilful seamen, and may yet lie helpless in mid-ocean, if there is no one on board capable of working out its reckoning and determining its course ; and a landsman, a boy or a woman may be able to do this by means of the learning taught in the schools, though quite unable to perform any of the

duties of the practical seaman. The ship is equally helpless without practical skill and without science. Both must be present. It is just so with farming. The farmer must know the practical operations of his art—how to plough, to harrow, to sow, to reap ; but he may know and industriously practice all these, and yet may be running his farm to ruin as surely as the seaman would his ship, if he knew not his course and distance. Here science comes to the aid of the farmer. It teaches him the nature and composition of his soil ; the materials of which he exhausts it in cropping ; the various requirements of different cultivated plants ; the nature and uses of manures ; the causes of sterility and impoverishment, and the cheapest and best modes for remedying the one and avoiding the other ; and the materials necessary to renovate lands that have been already exhausted.

Further, these teachings of science are not merely clever guesses and conjectures, but the results of long and patient enquiry into facts, made by the practical chemist or physiologist, who, each in his several way, is just as much a practical man as the farmer.

None of the arts have derived greater benefits from science, and especially from chemistry, than agriculture. Soils, manures and plants have been analyzed ; the causes of fertility and barrenness, of running out and impoverishment, the means of supply of the most valuable constituents of crops, the enemies and diseases of cultivated plants, and many similar subjects, have been investigated ; and the result has been that agriculture has become a scientific art, and has been brought to a pitch of profitable perfection that our grandfathers would have deemed chimerical. But knowledge of this kind

is yet only partially diffused. While in some countries, by the application of scientific knowledge, land that has been cultivated for ages is being brought back to its original fertility, and its produce vastly increased; in others, through neglect or ignorance, the most fertile regions are gradually becoming unproductive.

In our own country there can be no question that much has to be learned in this respect. The history of many, if not of most Canadian farms, is that of deterioration by exhaustive cropping—a process which, if not checked by agricultural improvement, leads to failure of crops, to poverty, to discontent, and to emigration of the farming population to other countries. Every one feels that to effect a change in this, the mind of the farmer must be reached in order that his practice may be improved. But that this may be effectually done, the rudiments of agricultural science must be taught to youth; and the question for the educator is—How, and to what extent, can this be done?

## § 2. *Agriculture in Schools.*

It must be admitted that it is not the province of the common school teacher to give instruction in trades or professions. It is his vocation to give that elementary training which is more or less useful in all walks of life, while special professional training belongs to schools established for such purposes, or to the practical man in his field or workshop; still it is a legitimate part of the business of the teacher, to connect, as far as may be, the subjects of his instruction with the practical work of life, and especially with those portions of it which are very generally

pursued. He cannot teach the practice of agriculture, —that must be done in the field,—but he can explain its theory, or, to speak more strictly, the natural laws on which its operations depend.

It is this scientific aspect of farming which can be taught in the schools. We can teach the bearing of modern scientific discoveries on the improvement of the art, and we can thereby elevate the profession itself, make it more attractive to young persons, and contribute not a little to the industrial wealth of the country. And let it be observed that while on the one hand agricultural education tends to the improvement of this important art, on the other it tends to the elevation of the school and the teacher, by more closely connecting education with the practical business of life, and improving and rendering more productive an art on which education mainly depends for its pecuniary support.

For such reasons as these, while in all the more enlightened countries there are special agricultural schools and colleges, and model farms, where the science of agriculture may be prosecuted in all its details, efforts are also made to introduce the elements of the subject into the Common Schools; and this more especially by directing the attention of teachers to its study in the Normal Schools, in which their professional training is received.

We must, however, carefully avoid encouraging delusive hopes or professing to do that which we cannot satisfactorily accomplish. We cannot, in the ordinary schools, train practical chemists or practical farmers. Practical chemistry is a profession to be studied by itself, and requires a long and careful apprenticeship for its successful pursuit. The



practical labor of the farmer can be learned only on a farm. The teacher must propose to himself the more humble task of instilling into the minds of the young the rudiments of the science of farming, and thereby preparing them better to understand its practical processes. Though the amount of agricultural knowledge communicated in this way is confessedly slender; though only the merest rudiments can be taught; yet the wide diffusion of even a small amount of knowledge of principles, and the thought and inquiry which this engenders, may be of incalculable value to the country. Admitting, then, that the elements of this great subject may thus be taught, let us inquire, 1st, what may be taught by the school teacher? and 2nd, what order shall he pursue in teaching it?

§ 3. *What may be taught by the School Teacher.*

1. He may teach of the *Plant*; of the elements of which it is composed; of the sources, in the earth and in the air, whence these are derived; of the kinds and proportions of food required by different plants, and the best means of supplying them; of the wonderful structure of the vegetable fabric, and the manner in which it forms from the material on which it subsists, the various products which it affords. On these subjects the discoveries of chemistry and physiology will enable him to impart much valuable and practical information.

2. He may teach of the *Atmosphere*; of its composition; of the stores of plant food which it contains, and from which the plant derives so important a part of its substance; and of its relations to the moisture which it holds in solution, or which is precipitated from it, as cloud, mist, dew, rain or snow.

3. He may teach of the *Soil*; of its derivation from the rocks of the earth; of its wonderful and complex composition; of its action on manures, in retaining them within it, and in parting with them to the roots of plants; of the causes of its fertility and barrenness; of its impoverishment by cropping; of its improvement by tillage, by draining, and by the application of manures. Here he will consider the decay of dead vegetable and animal matter, and its resolution into food for plants; the losses to which the richer organic manures are liable; and the nature and uses of mineral manures, with their various effects, whether directly as food for plants, or indirectly through the chemical changes which they induce in the soil.

4. He may teach of the several *Cultivated Crops* in detail, noticing their history, their modes of culture, their preferences in relation to soil, treatment, and manure; their produce—its uses to man and animals—and their enemies and diseases. He may, in like manner, proceed to apply the principles learned under these heads to the various modes of tillage, manuring and rotation.

5. He may teach of *Domestic Animals*; of the treatment needful for their health and comfort; of their labour and of its profitable development and employment, and of their marketable products,—milk, butter, cheese, eggs, wool and young or fatted stock of all kinds.

All these topics lie at the very threshold of agricultural knowledge and practice. They may be pursued to any extent, and the highest culture and mental powers may be applied to them; but their elements may be learned by young persons at school, and a foundation may be laid on which they may

build the highest and most successful prosecution of the most useful of all arts. In the discussion of every point presented, questions of cost, of economical administration, of due remuneration for labour, of interest on capital and of sufficient returns for skill must be predominant, for men do not engage in farming as an interesting and complex experiment in science, but as a means of livelihood, and of profitable and stable investment of money.

#### § 4. *Order to be pursued.*

In studying any scientific subject, more especially in its practical applications, it is necessary to follow some regular order of procedure ; and there are usually different plans which may be pursued, and which may severally have their special advantages and disadvantages. It is sometimes best to begin with general principles and rules, and illustrate them by examples ; sometimes best to begin with known facts, and follow these up to general principles. Further, in any complex subject it may often be difficult to explain one part of the subject without reference to others with which the learner may not be acquainted. Now, that we may ascertain the best order for proceeding with our present subject, let us consider the things with which we have to do. The objects of agriculture are to obtain from the soil the largest possible amount of valuable food for men and animals ; to preserve the soil in such a condition that it will produce other crops in future years, and to apply the food produced in the most economical and useful manner. In attaining these ends, the farmer has to do principally with cultivated plants, with soils, with manures, with domesticated animals, and with destructive vermin and diseases.

All these subjects the farmer naturally regards in the light of experience, and with reference to practical operations. What we have to do is to bring to bear on their explanation the facts and principles ascertained by chemistry, physiology, and natural history, and more especially by the first of these sciences. Agricultural chemistry, in short, is of more importance than agricultural physiology, botany, zoology, or geology, though all of these are useful. We shall, therefore, make this our basis, and bring in the other subjects as we proceed. Having laid for the learner a foundation of such physical and chemical knowledge as may appear indispensable, we shall consider the Plant, the Atmosphere, the Soil, and Manures; and having discussed these, shall proceed to apply the knowledge thus acquired, to the Crops cultivated by the farmer, leaving for treatment in a subsequent work all questions respecting Domestic Animals.

Our arrangement may thus be as follows:

I. We shall notice such general principles of Physics and of Chemistry as may be absolutely necessary for our purpose:—

Chapter 1. Forms of matter.

“ 2. Heat.

“ 3. Chemical principles.

“ 4. Chemical processes.

“ 5. Properties of substances most important in relation to agriculture.

II. We shall consider the Plant in the following aspects:—

Chapter 6. The structures and functions of plants.

“ 7. The organic products of plants.

“ 8. The ashes of plants.

III. We shall consider in

Chapter 9. The atmosphere as a source of plant food.

IV. We shall consider the Soil in the following particulars:—

Chapter 10. Its origin and classifications.

“ 11. Its composition and relation to plants.

“ 12. Its exhaustion by cropping.

“ 13. Its improvement by mechanical means.

“ 14. Its renovation by manures.

V. We shall consider the chief cultivated crops with their various habitudes and diseases, their management and their storage.

Chapter 15. Wheat, Oats, etc.

“ 16. Soiling and Silos.

We shall postpone for fuller separate treatment Fruit Trees, their cultivation and produce; and Domestic Animals, whether as working animals, or as furnishing dairy products, wool or animal food.

According to this arrangement the more theoretical part will come first; but the reader interested in the practice of agriculture should bear in mind that the earlier parts, though apparently less practical, nevertheless contain the principles necessary to the understanding of the rest.

X

### §5. *Uses of Agriculture in Schools.*

The advantages of such a course, to the young mind, are many and great. It leads to the consideration of all those processes by which the great Husbandman above produces out of the earth food for every living thing, as well as to those humble imitations of them by which man seeks to effect similar

results on a smaller scale. In this point of view, as a means of enlarging the mind, and enabling it to reason on natural causes, the subject well deserves the study even of those who have no direct connection with practical farming. It is, in short, an important branch of learning in natural science.

Such a course will, further, enable the young farmer to read with advantage the best works on his art, and to judge for himself as to the application of their statements to any particular case. Book farming is little respected by many good farmers, and, to some extent, deservedly so. Too often agricultural books and articles in agricultural periodicals state facts or experiments without appreciation of the conditions on which success or failure depends. They thus give, as truths generally applicable, special facts which are of limited value, or perhaps apply to exceptional cases only. They in this way mislead the simple practical man who trusts to them. Even good agricultural works require a certain amount of knowledge in those who read them. The plainest statements may be misapprehended by a reader not acquainted with the precise meaning of the terms in which they are expressed. The most carefully guarded explanations may be misunderstood and misapplied by similarly unlearned readers. It thus happens that for want of scientific precision in those who write or those who read, the book farmer often incurs the loss and disgrace of costly failures, which most unjustly bring scientific farming into disrepute, being caused, not by the errors of science, but simply by the want of science. The intelligent young farmer should have enough of scientific culture to enable him on the one hand to distinguish the half truths so often presented

from a complete statement of the facts and principles bearing on any particular case, and on the other to appreciate and understand the best scientific works on his profession.

The knowledge even of the elements of agricultural education will be sufficient to enable the farmer to decide as to the application of artificial manures, and to avoid the losses caused by error and fraud in the use or manufacture of such materials. It will enable him to consider the composition and properties of the soils with which he has to do, and to avail himself of the services of the practical chemist in their preservation and improvement. It will teach him to appreciate the requirements of the different crops and domesticated animals, the special uses of their varieties, and the diseases to which they are liable. It will give him enlarged views on agriculture as practised in various countries and under different circumstances, as susceptible of a vast variety of methods more or less valuable, and as intimately connected with natural laws. It will thus not only add to the productive value of his labor, but will make him love his art, and realize its true position as no mere mechanical drudgery, but a scientific and even learned profession. For the farmer is not a mere manual laborer. He has to do with soils of complex composition, liable to ruinous deterioration and susceptible of great improvement. He has to tend and rear vegetable and animal organisms of complicated and varied structures and habits. He is brought in every part of his work directly into contact with nature and its laws. He is, in short, the true alchemist, whose task it is to bring out of the earth, and of things cast aside as worthless by other artists, that most valuable of all products

— human food. His skill and knowledge make of the desert a fruitful field ; his ignorance and carelessness may reduce the most fertile fields to desolation. Above all, the farmer is an independent workman. Isolated on his farm, he has to judge for himself in many cases of doubt,—has to plan his own processes, and to adapt them to his own circumstances. In older countries, farming, like great manufactures, may have its planning done by a few heads, while the details may be carried out by hands skilled only in a few mechanical movements ; but the independent small farmers of a country like this must have the intelligence to manage as well as the skill to work.



## CHAPTER I.

### FORMS OF MATTER.

#### § 1. *Gases.*

*Experiment 1.* Instead of the glass top of a gem jar of one pint capacity, fit in a sound wooden plug of the same size and shape; and through the plug pass a tube of glass or metal, of a quarter of an inch bore and four inches long, so that it will project nearly two inches on each side of the plug, cementing it in air tight with sealing wax or glue. Insert an inverted test tube half full of water in a bottle of water; lower it into the gem jar, and screw the wooden top on tightly. Then blow through the tube into the jar. Then suck air out of the jar

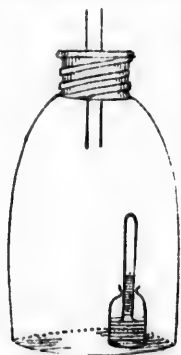


Fig. 1.

Why does the water in the tube rise and fall?

Air is a gas. All bodies whose physical properties resemble those of air are called gases. Gases expand as the limits which confine them expand. If a closed pint bottle full of water could be suddenly doubled in size, the water would not expand, it would still fill only one half of the bottle; but if a closed pint bottle filled with air, or any other gas, could be suddenly doubled in size, the air would expand, it would be found in every part of the bottle;—it would still fill the bottle. If the bottle, remaining tightly closed, could be repeatedly doubled in size, the air contained

in it would continually expand so as to fill it. This great expansibility of air and of all gases is associated with a corresponding compressibility. It is not possible to pump into a pint bottle filled with water another pint of water ; but it is possible, if the containing vessel be strong enough, to pump many pints of air at the ordinary pressure, into a pint bottle. Air thus compressed presses outward on every side and, if the additional pressure were removed, it would expand again to its original volume. A steel spring kept constantly bent will, after the lapse of a very long time, lose its elasticity, it will not spring back when the pressure is removed ; but air and all gases are permanently elastic.

More definitely we may say that the volume of a gas is inversely proportional to the pressure on each square inch of its surface, it being supposed that the temperature does not change. If then the pressure on each square inch of the surface of a gas be doubled or tripled, the volume of the gas will shrink to one-half or one-third of its former amount ; and if the pressure on each square inch of the surface be reduced to one-half, one-third or one-fourth of what it was, the gas will expand to twice, three times or four times its first volume.

However, the elasticity of a gas is not unbounded. Its expansibility is very great, but theoretically it has its limits. Its compressibility is very great, but almost every gas by the combined influence of very great pressure and very intense cold has been reduced to the liquid form, and then the law of compressibility is profoundly modified.

*Arithmetical Exercises.*

1. Under a pressure of 10 lbs. on the square inch, a certain amount of gas fills two cubic inches; what space will it fill under a pressure of 20 lbs. on the square inch? of 25 lbs.? of 40 lbs.? of 5 lbs.? of 1 lb.? of  $\frac{1}{2}$  lb.?

2. One cubic foot of air, under an initial pressure of 15 lbs. on the square inch, is successively compressed into the space of 432 cubic inches, 108 cubic inches, 100 cubic inches, 50 cubic inches and 12 cubic inches; what pressure is exerted on each square inch of surface at each of these stages of compression?

3. One cubic inch of gas under a pressure of 2,000 lbs. per square inch is permitted to expand to 4, 5, 10, 20, 90 cubic inches; to one-fourth, one-third, one-half of a cubic foot; to one, two, three cubic feet. What is the pressure per square inch at each stage of expansion?

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Air like every other material substance has weight. At a temperature of 60° F., and under a pressure of 14.715 lbs. on the square inch, one cubic inch of air weighs .31 grains. Some gases are heavier than air, some are lighter. The following numbers give the weights of a few of the principal gases, air being 1; oxygen 1.1088, hydrogen .0693, nitrogen .9702, chlorine .246, carbon dioxide 1.5246. These numbers are called the specific gravities of the several gases. To find the weight of any volume of either of these gases, find the weight of an equal volume of air in the given circumstances, and multiply by the specific gravity as given above.

*Experiment and Examples.*

Experiment 2. Make a cylindrical paper bag large enough to hold about a pint, and counterpoise it in a delicate balance. Then pour into it some carbon dioxide as prepared in experiment 71.

4. How many times heavier than hydrogen is air?

5. What is the weight of a cubic foot of air at standard temperature and pressure?

N.B.—Standard temperature and pressure are stated above;  $60^{\circ}$  F., and 14.715 lbs. on the square inch. Unless otherwise stated all subsequent questions presuppose standard temperature and pressure.

6. How many cubic feet of air weigh one pound?

N.B.—7,000 grains make a pound.

7. What is the weight of a cubic foot of each of the following gases; oxygen, hydrogen, nitrogen, carbon dioxide and chlorine?

8. If a volume of air weigh one ounce, what would one such volume of oxygen weigh? two such volumes of hydrogen? three of nitrogen? four of chlorine? five of carbon dioxide?

9. How many cubic inches of air, of oxygen, of hydrogen, of nitrogen, of chlorine and of carbon dioxide weigh one grain?

10. If one volume of air weigh one ounce, how many equal volumes of oxygen, of hydrogen, of nitrogen, of carbon dioxide and of chlorine would weigh one ounce?

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The specific gravity of a gas may be determined by comparing either the weights of equal volumes of that gas and of air, or the volumes of equal weights of that gas and of air.

*Examples.*

11. What is the specific gravity of a gas of which one cubic inch weighs .62 grains? What if one cubic inch weighs .35 grains? .4628 grains? .5826 grains? What if one cubic foot weighs 370 grains? 638 grains? 1,000 grains?

12. What is the specific gravity of a gas of which one grain fills 1 cubic inch? 2 cubic inches? 3.2258 cubic inches? 2.9093 cubic inches? 1.3113 cubic inches? 46.5484 cubic inches?

13. A certain weight of air fills one cubic foot; the same weight of hydrogen fills 14<sup>3</sup> cubic feet. What is the specific gravity of hydrogen?

X 14. One pint of air weighs 17.4257 grains, and of carbon dioxide 26.5672 grains. The weight of 1,000 cubic feet of air is 7.6526 lbs., and of hydrogen is .5304 lbs. Find the specific gravities of carbon dioxide and hydrogen. = 1.5, 1.0693

15. If one volume of air weigh one, what would one volume of a mixture of equal volumes of oxygen and hydrogen weigh, and what one volume of a mixture of two volumes of oxygen with three of nitrogen?

N.B.—These answers will give the specific gravities of the several mixtures.

16. What is the specific gravity of a mixture of two volumes of hydrogen and one of oxygen? of equal volumes of oxygen and nitrogen? of one-fifth by volume oxygen and four-fifths nitrogen? of ten volumes oxygen and thirty-seven volumes nitrogen?

17. How many cubic inches are there in a mixture of one grain of oxygen and one grain of hydrogen? How many in two grains of air? What then is the specific gravity of the mixture? See question 9.

18. What is the specific gravity of a mixture of three parts by weight of oxygen with two parts of hydrogen? of one part of oxygen with three parts of nitrogen? of four parts of carbon dioxide and five parts chlorine?

19. Sometimes it is said that air consists of five parts by weight of oxygen and sixteen parts nitrogen. Find the specific gravity of the mixture, and from it state whether more oxygen or more nitrogen should be introduced into the mixture in order to reduce the specific gravity to that of air.

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Air at the surface of the earth is pressed down by the weight of all the air above it. It is, therefore, under a pressure of about  $14\frac{3}{4}$  lbs. to the square inch, which acts equally in every direction.

### *Experiments.*

Exp. 3. Fill a tumbler quite full of water; cover it with a piece of paper larger every way than the top of the tumbler. Take the tumbler in your left hand, place the palm of your right hand on the paper, and turn the tumbler upside down. What would happen if you were to remove your right hand? Remove it and see. The pressure of the air on the lower side of the paper is greater than the weight of the water on the other side; therefore the paper is sustained.

Exp. 4. While the tumbler is still inverted and full of water dip it into a saucer full of water; then withdraw the paper. What prevents the water from running out now? The pressure of the air on the surface of the water in the saucer, for evidently the water in the tumbler cannot run out without pushing up the surface of the water in the saucer.

Exp. 5. Lift the edge of the tumbler a little, but not enough to raise it above the surface of the water in the saucer. Put one end of an open pipe, a straw, for instance, under the edge of the tumbler and blow into it. You can thus fill the tumbler with air from the lungs by the displacement of the water. Would it be easier or harder to blow air into the tumbler, inverted and full of water, if the tumbler were taller? Consider the subject carefully and answer for yourself.

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The pressure of the air varies a little from time to time with the varying states of the weather. It may increase in very fine settled weather to as much as 15 lbs. on the square inch, or sink in stormy weather to  $14\frac{1}{4}$  lbs. The varying pressure of the air is measured by the barometer, an instrument in which the weight of a column of mercury in a glass tube is balanced against the pressure of the air. When the top of the column of mercury in the tube is 30 inches above the level of the mercury in the reservoir, and the temperature of the air is  $60^{\circ}$  F., the pressure of the air is 14.715 lbs. on the square inch; and the pressure is greater or less by .49 lb., nearly half a pound, on the square inch for every inch that the mercury rises or falls. Because the pressure of the air is greatest in fine settled weather, and least in stormy weather, the barometer is often used as an indicator of change of weather, and is, therefore, sometimes called a weather glass. A rising of the mercury shows increasing atmospheric pressure, and, therefore, indicates a tendency to fine weather; a falling barometer shows diminishing atmospheric pressure, and indicates approaching storms, with the fall of rain or snow.

But it requires some experience and skill to read aright the indications of the barometer.

If a barometer be carried to a height above the surface of the earth, the column of mercury falls as the height increases; because there is a less and less weight of air above the instrument, as it is carried upward, and so the air around it is less and less compressed. The atmospheric pressure on each square inch becomes less. Hence the barometer is often used to measure the height of mountains.

*Examples.*

20. Show that if a height of 30 inches of mercury indicates a pressure of 14·715 lbs. on the square inch, one inch indicates a pressure of 4905 lb. on the square inch.

21. What atmospheric pressure on each square inch is indicated by each of the following heights of the mercurial column in a barometer; 31 inches? 30·5? 29·6? 28·4?

22. In the hurricane of November 29th, 1836, at 9 a.m., the barometer stood in London at 29·3 inches; it then began to fall rapidly, and at noon stood at 28·82 inches. In half an hour the storm broke with great gusts of wind and heavy rain. At 2 p.m. the barometer had risen to 29·35, the storm began to subside, and was soon succeeded by a calm. What was the pressure on the square inch at 9 a.m., at noon, and at 2 p.m.?

23. In the midst of a typhoon, at Hong Kong, the barometric height was 28·5 inches; what was the atmospheric pressure on a square foot of surface?



24. On the summit of Sara-Urcu Mr. Whimper found the height of the barometer to be 17·23 inches ; what was the pressure of the air on the square inch ?

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It must be remembered that as any gas becomes denser, when compressed, in proportion to the pressure, proper allowance for the effect of barometric variation must be made, when calculating the weight of any volume of air. Allowance for change of temperature must also be made ; but this is a point to be afterwards considered.

*Examples.*

25. What is the weight of the air in a room 25 feet long, 15 feet wide and 10 feet high, at a temperature of  $60^{\circ}$  and under a barometric pressure of 29·5 inches ?

26. Under a pressure of 8 lbs. to the square inch more than the barometric pressure, which at the time is 30 inches, and at a temperature of  $60^{\circ}$ , a bubble of air containing one cubic inch is formed ; what is its weight and to what dimensions would it expand, if the extra pressure were removed ?

27. A balloon contains 10,000 cubic feet of hydrogen when it has ascended to such a height that the barometer has fallen to 20 inches. What weight can it sustain at that elevation, the temperature being  $60^{\circ}$  ?

N.B.—It can sustain the difference of the weight of 10,000 cubic feet of air and 10,000 cubic feet of hydrogen, under the given conditions.

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One gas expands into the space occupied by another gas in the same way as it would into an empty space, but more slowly. If for example a quart bottle of

carbon dioxide were connected by an open tube with an empty quart bottle, the carbon dioxide would instantly expand into the empty bottle so as to share the gas equally between the two bottles, the pressure and the density being half as great in each bottle as it was in the first bottle in the beginning. But if two bottles equal in size, one filled with carbon dioxide at a pressure of 15 lbs. per square inch and the other with oxygen at a pressure of 60 lbs. per square inch, were placed in communication with each other, the carbon dioxide, somewhat more slowly than in the former case, would expand into the oxygen bottle, and the oxygen into the carbon dioxide bottle, so as to become completely intermixed. The pressure of carbon dioxide in each bottle would be  $7\frac{1}{2}$  lbs. per square inch, and that of oxygen in each 30 lbs., so that the total pressure of gas in each bottle would be  $7\frac{1}{2} + 30 = 37\frac{1}{2}$  lbs. The density of the mingled gases will be found by an obvious calculation to be 1.1919 times that of air at the same temperature and pressure; for the volume of oxygen in the mixture is evidently four times that of the carbon dioxide it contains.

28. Two volumes of carbon dioxide at a pressure of 80 lbs. per square inch, are permitted to expand into four volumes of hydrogen at a pressure of 50 lbs; what is the resulting pressure?

29. What would be the weight of one cubic foot of the mixture in the preceding example, the temperature being  $60^{\circ}$  F.?

30. Four volumes of nitrogen are mixed with one of oxygen under a pressure of 35 lbs. per square inch. What pressure does each gas exert? and what is the weight of each gas in a cubic foot of the mixture?

## § 2. *Liquids.*

Water is a liquid. Liquids are unable to maintain a definite shape. Their particles are moved about by the slightest force, so that when a liquid is poured into any vessel, it arranges itself into a mass of which the upper surface is parallel to the surface of the earth, and the sides and lower surface take the shape of the containing vessel. This is true whatever may be the shape of the containing vessel, and no matter of how many parts, communicating at the bottom, that vessel may consist. Therefore, if two cups removed from each other by any distance be joined by a pipe, every part of which is lower than the tops of the cups, and if water or any liquid be poured into one of the cups, it will run through the communicating pipe, and stand finally at the same level in each of the cups.

### *Experiment.*

Experiment 6. Insert glass tubes air tight into the open ends of a rubber tube full of water, raise the glass tubes and lower them variously and observe the levels of water in them.

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At different depths in a liquid the pressure which it exerts on a square inch of an immersed surface will be different. That pressure is always equal to the weight of a column of the liquid as high as the depth of the submerged surface and standing on a base one inch square. If there be any pressure exerted on any part of the surface of a liquid completely enclosed in a full vessel, an equal pressure additional to that due to the depth of the liquid will be transmitted to every part of the vessel and its contents.

*Examples.*

31. One cubic inch of water at a temperature of  $60^{\circ}$  weighs  $252\frac{1}{2}$  grains; how many cubic inches are there in an imperial gallon of water, which weighs 10 lbs. ?

32. What does a column of water 33 feet high, and one square inch in section, weigh ?

33. If the inverted tumbler in experiment 3 were three inches high, and cylindrical in shape,\* and the area of its mouth four square inches, what would be the downward pressure due to the water ? what would be the upward pressure due to the atmosphere ? and what is the excess of upward pressure that keeps the paper up ?

34. If the tumbler were 3 feet 6 inches high, what would be the difference of pressures ?

35. Had the tumbler been 30 feet high, what pressure would have sustained the paper ?

36. Had it been 35 feet high, what would the difference of pressure have been, in which direction would it have acted, and what would have been the result ?

37. What is the pressure per square inch of a column of water 35 feet high, when there is no atmospheric pressure on the surface of the water ? What is the height of the barometer when the pressure of the air just equals that of such a column of water ? What is the pressure on a surface one foot square sunk 33 feet in water, on the surface of which the atmospheric pressure is  $14\frac{3}{4}$  lbs. per square inch ?

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\* The shape of the tumbler is of no importance; but, if it be cylindrical, pupils readily see that the downward pressure is equal to the weight of water.

38. The sides of a box are so strong that a pressure of 50 lbs. on the square inch will just crush it; if it be full of air at a pressure of 15 lbs. on the square inch, how deep must it be sunk in order to crush it by the pressure of water at  $60^{\circ}$  F., when the height of the barometer is 29.75 inches? and how far when the height of the barometer is 30.3 inches?

N.B.—When full of air at a pressure of 15 lbs. on the square inch, it will require an outside pressure of 65 lbs. per square inch to crush it.

39. If the box in the preceding exercise had been empty of air before sinking, and the height of the barometer had been 30 inches, at what depth would it have been crushed?

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From the surface of almost all liquids vapour is given off. The amount of vapour that arises into a given space from any liquid is determined partly by the nature of the liquid itself, partly by the temperature. It is the same in amount whether the space into which it rises is empty, or is filled with other gases or vapours. When the definite amount of vapour which can rise into a given space has been formed, no more vapour can ascend from the exposed surface of the liquid, and the space above it is said to be saturated with vapour. If then the liquid be removed, and the space saturated with vapour be increased in volume, the temperature remaining constant, the vapour will expand to fill the enlarged space precisely as a gas would do. But if the space saturated with vapour be contracted, that amount of vapour which before filled the space lost by contraction, will be deposited in droplets of liquid, either as a fine mist suspended in the air filling the space, or

settling as a dew on the sides of the containing vessel. The particles of a vapour rising into a confined space filled with other gases or vapours crowd in between other particles, and add their own density and pressure to the density and pressure of the gases and vapours previously occupying the space.

### *Experiment.*

Experiment 7. Seal up in a gem jar a lump of quicklime half as large as an egg, and also an uncorked bottle containing a teaspoonful of water. After a few days examine it. Where has the water gone? Is the lime heavier than it was? How much heavier?

Some liquids absorb some gases. At a given temperature one volume of a given liquid will absorb a definite number of volumes of a given gas. The number of volumes of gas absorbed remains the same however the pressure to which the gas is subjected, increases or diminishes. At the freezing point,  $32^{\circ}\text{F.}$ , one volume of water absorbs .02 volumes of nitrogen, .041 of oxygen, 1.8 of carbon dioxide and 1049.6 of ammonia.

### *Examples.*

40. How many quarts of nitrogen, oxygen, carbon dioxide and ammonia will be dissolved by one gallon of ice-cold water?

41. How many cubic inches of nitrogen, of oxygen and of carbon dioxide can be absorbed by one cubic foot of ice-cold water?

42. If the barometric pressure be 30 inches, what weight of oxygen, of nitrogen and of carbon dioxide will be absorbed by 100 cubic inches of ice-cold water?

N.B.—The weight of 100 cubic inches of air at 30 inches pressure and  $32^{\circ}$  temperature is 32.76 grains.

43. If in the preceding question the barometric pressure were to be halved, doubled, to become 29 inches and 31 inches respectively, what in each case would be the weights of the absorbed gases?

In a mixture of gases each exerts the pressure due to its volume, and is absorbed independently of the other gases present. Thus, if a mixture of one volume of carbon dioxide and one of nitrogen exert together a barometric pressure of 30 inches, each exerts a pressure of 15 inches, and the amount of each gas absorbed by ice-cold water will be the same as if it alone were pressing on the surface of the water.

*Examples.*

44. At a pressure of 30 inches how much carbon dioxide, and how much nitrogen, will be absorbed from a mixture of equal volumes of these gases, by a cubic foot of ice-cold water? Give the answer both in cubic inches at standard pressure and in grains.

45. In a mixture of four volumes of nitrogen and one of oxygen, at a barometric pressure of 30 inches, how much of each gas will be absorbed by 100 cubic inches of ice-cold water?

The specific gravity of a liquid is its weight compared with the weight of an equal bulk of water at  $60^{\circ}$  F. It is expressed by the number which multiplying the weight of the water gives the weight of an equal bulk of the liquid. It is frequently found by weighing a bottle when empty, again when full of distilled water at  $60^{\circ}$ , and a third time when full of the

liquid under consideration ; then the weight of the bottle full of that liquid less the weight of the bottle, divided by the weight of the bottle full of water less the weight of the bottle, gives the specific gravity of the liquid. III

*Example.*

46. A bottle which when empty weighs 2.5 oz., when full of distilled water weighs 4.5 oz., full of alcohol 4.1 oz., of sulphuric acid 6.1 oz., of glycerine 5 oz., of mercury 29.6 oz. ; what is the specific gravity of each liquid ?

The specific gravity of a liquid is sometimes found by taking advantage of the principle that a solid immersed in a liquid loses of its weight an amount precisely equal to the weight of an equal bulk of the liquid ; e.g., since one cubic inch of water weighs  $252\frac{1}{2}$  grains, one cubic inch of some substance which out of water would weigh 750 grains, would under water weigh only  $750 - 252\frac{1}{2} = 497\frac{1}{2}$  grains.

*Example and Experiment.*

47. A glass stopper which weighs one ounce in air, weighs .58 oz. when immersed in water, .66 oz. when immersed in a certain sample of alcohol, .25 oz. in sulphuric acid, and .48 oz. in glycerine ; find the specific gravity of each of the liquids mentioned.

Exp. 8. Find the specific gravity of a sample of coal oil in both ways described above, and see if your methods give concordant results ? Your answer should be nearly .8.



### § 3. *Solids.*

Solids resist change of form. Their particles cohere more or less tenaciously. It requires considerable force to drive a ploughshare through the earth. It requires a much greater force to break asunder solid rock. The farmer has to do with soils which consist of solid particles more or less comminuted, of sand, clay, gravel and vegetable debris, of which the several fragments do not strongly adhere to one another.

Solids in a divided state have special relations to liquids and gases. The surfaces of many solids attract both gases and liquids. Since a finely divided solid exposes a far greater surface than the same solid in a compact state, many granulated, porous or cellular solids absorb considerable quantities of both gases and liquids. Thus, one cubic inch of box-wood charcoal absorbs 90 cubic inches of ammonia, 35 of carbon dioxide, 9.2 of oxygen, 7.5 of nitrogen, and 1.75 of hydrogen. Cocoanut charcoal, doubtless because of its minuter cells and therefore more extended surface, is almost twice as absorbent as box-wood charcoal.

#### *Experiment.*

Exp. 9. Fill a gem jar, prepared as in Exp. 1, with  $\text{CO}_2$  as in experiment 71. Slip a piece of rubber tube over the end of the tube in the plug. Drop about a cubic inch of charcoal that has been recently strongly heated, into the jar; quickly seal up the jar, letting the end of the rubber tube dip into some water. Why does the water rise in the rubber tube?

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Some solids have a surface attraction for some liquids. A piece of wood or of stone immersed in

water is wetted by it ; some of the water clings to it when withdrawn from the water. Water creeps a little way up the surface of a clean glass cup in which it is contained. It rises a considerable distance in a fine glass tube. In the same way if one end of a chip of wood or the corner of a porous brick be dipped into water, the chip or the brick will soon become wet at a noticeable height above the water level. This surface attraction of solids for liquids is called capillary attraction.

### *Experiments.*

Exp. 10. Weigh a thin piece of thoroughly clean glass, dip it in water, take it out, shake it well and weigh it again. Do the same thing with a piece of glass which you have wiped with a slightly greasy rag.

Exp. 11. Lay a strip of thick pasteboard, one-quarter of an inch wide, along one edge of a clean pane of glass. Lay another similar pane of glass on it. The two panes will touch at one edge and be separated by the pasteboard at the other edge. Wrap some thread around the two panes to bind them together. Lay them down in a little coloured water. Then tilt them up so that the pasteboard strip is upright while the lower edges of the panes stand in the water. Observe the level of the water between the two panes.

Exp. 12. Fill a cup with water. Wet a strip of cotton an inch wide and six inches long, put one end into the water in the cup and let the other end hang down outside three or four inches. See how long before the cup will be empty.

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Many solids are dissolved by liquids; especially by

water, which slowly corrodes and wastes away even rocks and stones. The solvent action of water is often much aided by the gases and solid substances dissolved in it. Limestone is almost insoluble in pure water, but water holding carbon dioxide in solution dissolves limestone in relatively large amounts. Many of the great caverns of the world have been excavated in limestone rock by the solvent action of water charged with carbon dioxide.

When water holding a solid in solution evaporates slowly, the solid left behind frequently arranges itself into masses sometimes very small, sometimes of considerable size, of definite form, bounded by flat surfaces. These definitely shaped masses are called crystals. Thus if we throw common salt into water, it is dissolved. If a drop of this solution of salt be placed on a piece of glass, as it dries the particles of salt unite, and become regularly arranged, forming little transparent cubes. This is crystallization, and it may take place either in bodies which have been dissolved in water, or in those which have been melted or dissipated by heat.

#### *Experiment.*

Exp. 13. Dissolve half an ounce of alum in two tablespoonfuls of boiling water. Let two or three twigs dip into the solution and set it aside to cool slowly. When cold lift the twigs out.

4. The specific gravity of a solid is expressed by the number which multiplying the weight of an equal bulk of water gives the weight of the solid. As already stated on page 29, a body immersed in water loses of its weight an amount precisely equal to the

weight of an equal bulk of water. Therefore to find the specific gravity of any substance heavier than water and insoluble in it, weigh first in air, then when immersed in water, and divide the weight in air by ~~the weight in water.~~

*The diff*

*Examples and Experiments.*

48. A mass of quartz weighed 656.5 grains in air and 404 grains in water; what was its volume, and what its specific gravity? *26.*

49. A piece of marble weighed 416 grains in air and 262 grains in water; what was its volume, and what its specific gravity? *2.7.*

Exp. 14. Arrange a little scale, beneath the scale pan of a balance, hanging by a fine wire or horse hair into some water in a tumbler. Weigh a fragment of limestone in air in the upper scale, then transfer it to the lower scale under water and weigh again. Then calculate the specific gravity. It should be about 2.7.

Exp. 15. Find the specific gravity of some iron wire and of a twenty-five cent piece. You should get very nearly 7.8 and 10.

## CHAPTER II.

### § 1. HEAT.

#### *Temperature.*

Under almost all circumstances bodies expand with heat. Gases, liquids and solids swell as they grow warmer, and shrink as they cool.

#### *Experiments.*

Exp. 16. Drop a cold iron ring on to the smaller end of a round rod which tapers very slightly and which the ring fits; mark how far down it goes; take it off; heat it quite hot, but not red hot, and drop it on again; mark how far it goes; let it cool on the rod; try to draw it off again. Why does the blacksmith make a wagon tire hot, before he puts it on the wheel?

Exp. 17. Through the cork of a bottle pass air tight, a long, small glass tube open at both ends; fill the bottle with inky water and cork it with the cork and tube. Let there be enough water to rise a little way in the tube. Warm the bottle; cool the bottle.

Exp. 18. Empty almost all the water out of the bottle, and turn it upside down so that the end of the tube dips into another bottle of water. Then alternately warm and cool the upper bottle, while the end of the tube is immersed. Gases expand much more than liquids.

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✓ If a small bottle with a long narrow neck be nearly filled with mercury, quicksilver, and be placed in a

pail of water containing lumps of ice, the mercury, contracting in bulk, will shrink down to a certain level in the neck of the bottle, and will stand at that level as long as any ice remains unmelted in the pail. If we were to mark that level by a scratch, we should have the means of determining that particular temperature at any future time. If we were to plunge the same bottle with the same amount of mercury in it into freezing water at any time, we should find that the mercury would shrink down to the same mark exactly. If we were to leave the bottle in the open air on a chilly day in autumn, and the mercury were to sink to the marked level, we should say that the air was just freezing cold. If it sunk below that level, we should know that the day was colder than mere freezing, and if it did not shrink quite so far down, we should know that the weather was not quite cold enough for frost. For obvious reasons our bottle would give us more exact indications, if its neck were made very small and very long; and if the air were pumped out of the neck, and the top of the bottle were tightly sealed, dust could not enter nor mercury escape. Such a very long necked bottle, nearly full of mercury and hermetically sealed, is called a thermometer, and is used for the purpose of recording temperature. So far as yet described our thermometer would mark accurately only one temperature, the freezing point; but, if we plunged it into boiling water, the mercury would rise far up in the neck, or as we shall call it in future, the tube of the thermometer. We might then mark this second height by another scratch, and should then be able to find out by our thermometer whether a hot liquid was as hot as boiling water, hotter or less hot. In the

thermometer commonly used here, the Fahrenheit thermometer, the distance between the freezing and the boiling points is divided into 180 equal parts called degrees, and an equal graduation is continued above and below these points. Thirty-two of these degrees below the freezing point is marked 0, and is called zero. Degrees of temperature lower than this are said to be below zero, and degrees of temperature higher than this are said to be above zero. To distinguish degrees above from those below zero the latter are printed with the minus sign before them; so  $-15^{\circ}$  means a temperature 15 degrees below zero. The freezing point of water then is marked  $32^{\circ}$ , and the boiling point ( $32^{\circ} + 180^{\circ}$ ) is necessarily  $212^{\circ}$ . Many other definite degrees of temperature have been observed and recorded. Mercury freezes at  $-39^{\circ}$ . It is not certain that a lower temperature than  $-60^{\circ}$  has ever been observed in the open air, or a higher than  $118^{\circ}$ . The temperature of the inside of the closed mouth of a healthy man is from  $98^{\circ}$  to  $100^{\circ}$ . Lead melts at  $594^{\circ}$ . Mercury boils at  $662^{\circ}$ . Iron becomes red hot a little under  $1,000^{\circ}$ , and cast iron melts at a temperature less than  $3,500^{\circ}$ .

## § 2. *Expansion.*

Gases expand with great regularity as the temperature rises. For every degree above or below the freezing point the volume of any gas under constant pressure increases or contracts by 1-491 part of its volume at the freezing point, which is the same as 1-519 part of its volume at  $60^{\circ}$ . It will be readily inferred that the pressure of a gas contained in a confined space will diminish or increase in the same proportion with fall or rise of temperature.

Let pupils verify by calculation the statement that 1-491 part of the volume of a gas at the freezing point is equal to one 1-512 part of its volume at  $60^{\circ}$ .

*Examples.*

50. To what volume would 3 cubic inches of air at a temperature of  $32^{\circ}$  expand, under constant pressure, if raised to the temperature of boiling water? to the melting point of lead? to the boiling point of mercury? to  $1,000^{\circ}$ ? to  $3,500^{\circ}$ ?

51. At what temperature would any volume of gas become twice, three times, four times its volume at  $32^{\circ}$ , if the barometric pressure remained constant?

52. At what temperature, pressure remaining unchanged, would five cubic inches of air at  $60^{\circ}$  shrink to three cubic inches. Verify your answer by finding what volume three cubic inches would give if raised from the temperature found in your answer, first to  $32^{\circ}$ , and then to  $60^{\circ}$ .

53. Air is introduced to the heater of a hot air engine at a temperature of  $60^{\circ}$  and a barometric pressure of 30 inches; to what temperature must that air be raised in order to exert a pressure of 10 lbs. per square inch above the pressure at which it was introduced?

54. What barometric pressure would be exerted by air which, having been sealed up in a bottle, at a temperature of  $32^{\circ}$  and a pressure of 30 inches of mercury, is then raised to a temperature of  $100^{\circ}$ ?

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As all gases expand equally with equal increase of temperature, the specific gravity of gases, compared with air or with hydrogen is the same at all temperatures; for, although the gas to be compared grows



lighter with increase of temperature, the standard gas with which it is compared grows lighter proportionally. But the weight of a given volume of any gas varies with the temperature. Thus, that volume of air which weighs 491 grains at  $32^{\circ}$  expands to  $\frac{511}{491}$  of that volume when heated to  $60^{\circ}$ ; therefore a volume at  $60^{\circ}$  equal to the first volume will weigh only  $\frac{491}{511}$  of 491 grains; i. e. 464.5 grains.

*Example.*

55. Find the weight of 100 cubic inches of air under a barometric pressure of 30 in., at  $32^{\circ}$ , at  $40^{\circ}$ , at  $60^{\circ}$ , at  $70^{\circ}$ , at  $80^{\circ}$ , at  $100^{\circ}$ , at  $212^{\circ}$ .

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Liquids in general contract and expand much less than gases, when subjected to similar changes of temperature. They differ greatly from one another in this respect, and the laws governing their change of volume are very complex. Water for example is densest at a temperature of  $39^{\circ}$ . Both in cooling below and in being warmed above that temperature it expands, and so becomes lighter. Therefore the layers of water at  $39^{\circ}$  sink to the bottom of the containing vessel, whether other layers are colder or warmer than they, so that in fresh water the depths are at a temperature of  $39^{\circ}$  both in summer and in winter.

Water suddenly expands in the act of freezing; 100 cubic inches of water at  $39^{\circ}$  become 109 cubic inches of ice. Hence alternate thawing and freezing disintegrates clods of earth, and even porous stones; in the same way the formation of ice in a pitcher of water bursts it.

### § 3. *The Unit of Heat.*

While a thermometer shows how hot any body is, it does not tell us how much heat there is in that body. If a thermometer be immersed in a pint of boiling hot water, or in a gallon of such water, it will indicate the same temperature, namely,  $212^{\circ}$ . But clearly a gallon of hot water contains eight times as much heat as a pint of water at the same temperature. The thermometer tells us how hot the water into which it is plunged is in any case, but it gives no direct information about the amount of heat present, as that depends partly on the quantity of water. In measuring amounts of heat the unit adopted is the amount of heat required for raising one pound of ice-cold water one degree in temperature. The amount of heat needed to raise one pound of water one degree in temperature is nearly the same at all ordinary temperatures, and may for practical purposes be reckoned as precisely the same. It follows that to raise two pounds of water one degree in temperature would require two heat units, and to raise five pounds of water  $10^{\circ}$  in temperature would require 50 heat units.

#### *Examples and Experiment.*

56. How many heat units are required to raise 15 lbs. of water from  $60^{\circ}$  to  $75^{\circ}$ ?

57. Ten lbs. of boiling water cool to the freezing point; how many heat units are given out?

58. Twenty lbs. of ice-cold water are mixed with 10 lbs. of boiling water; what is the temperature of the mixture? How many heat units are lost by the boiling water and gained by the icy water?

59. What weight of boiling water must be poured into 20 oz. of water at  $60^{\circ}$ , in order that the mixture

may be at a temperature of  $100^{\circ}$ , and how many heat units will be transferred from the hotter to the colder water ?

60. If 12 lbs. of water be put on a stove where it gains two heat units per second, how long will it take to rise from  $40^{\circ}$  to the boiling temperature ?

61. A tub containing 12 gallons of boiling water loses 150 heat units a minute ; in what time will it cool to  $120^{\circ}$  ? See example 31.

62. An iron pot containing 12 lbs. of water at a temperature of  $40^{\circ}$  is set on a stove where it gains two heat units a second ; how long before the water will be boiling hot, if the pot requires as much heat to warm it as half a pound of water ?

63. A cubic foot of water weighs  $62\frac{1}{2}$  lbs. ; half a cubic foot of water set on a fire, ice-cold, rose to  $100^{\circ}$  in ten minutes ; how many heat units did it gain per minute ?

Exp. 19. Mix known volumes of boiling water with known volumes of ice-cold water ; observe the temperatures, and compare with the results of calculation.

#### § 4. *Specific Heat.*

Equal weights of different substances require different amounts of heat to raise them equally in temperature. Water requires more heat than an equal weight of any other liquid or solid substance to raise it one degree in temperature. One heat unit, as we have seen, will raise one pound of water one degree ; but it will raise one pound of iron  $9^{\circ}$ , or nine pounds of iron  $1^{\circ}$ , and it will raise 34 lbs. of lead  $1^{\circ}$ , or 1 lb. of lead  $34^{\circ}$ . The capacity of water for heat, or, as it is generally expressed, the specific heat of water, is 9 times that of iron and 34 times that of lead. Water

being made the standard and its specific heat indicated by unity, the specific heat of iron is, therefore,  $\cdot 1111$ , and that of lead is  $\cdot 0294$ . The specific heat of water being the greatest of all substances except hydrogen, it absorbs more heat in getting warm, and gives out more heat in cooling, than any liquid or solid. Hence on the afternoon of a hot day at the seaside the sea is cooler than the land, and early in the morning of a cool night the sea is warmer than the land. Early frosts that may do considerable damage a mile or two inland, are not felt near the shores of large rivers or lakes. The climate of the interior of continents experiences more extreme temperatures both of heat and cold than islands and peninsulas in the same latitude. Arable land, by reason of the water it absorbs, heats up and cools down much less quickly than bare dry rock or arid sands.

*Examples and Experiment.*

64. Five pounds of iron at a temperature of  $200^{\circ}$  are immersed in 10 lbs. of ice-cold water ; to what temperature will the water be raised ?

N.B.—As the specific heat of water is 9 times that of iron, five lbs. of iron contain as much heat as  $\frac{5}{9}$  lb of water. The question then is equivalent to this:—if  $\frac{5}{9}$  lb. of water at  $200^{\circ}$  be poured into ten pounds of ice-cold water, what will be the resulting temperature ?

65. A mass of lead weighing 31 lbs. and being at a temperature of  $40^{\circ}$  is heated to  $108^{\circ}$  ; how many heat units are absorbed ?

66. An iron kettle weighing 9 lbs. is emptied of boiling water ; then 10 lbs. of water at  $58^{\circ}$  are at once poured into it ; what will the temperature of the water become, and how many heat units will the kettle impart to the water ?

67. If three vessels each contain three ounces of water at a temperature of  $65^{\circ}$ , and one ounce of water at a temperature of  $212^{\circ}$  be poured into one vessel, one ounce of iron at  $212^{\circ}$  immersed in another, and one ounce of lead at  $212^{\circ}$  in the third, what will be the resulting temperature in each case ?

Exp. 20. Test the correctness of the foregoing answer by experiment thus : tie strings to an ounce of iron wire coiled tightly, to an ounce of sheet lead and to a corked bottle containing an ounce of water. Then immerse all three in boiling water long enough to become of the same temperature ; lift them out by the strings and empty the water and plunge the iron and lead into separate vessels each containing three ounces of water at the temperature of  $65^{\circ}$ . When time enough has been given for the equalization of temperature of the contents of each vessel take the temperatures.

### § 5. *Latent Heat of Water and of Steam.*

If one pound of ice at  $18^{\circ}$  below zero be exposed to a source of heat that furnishes one heat unit per second, since the specific heat of ice is only one half that of water, the ice will be warmed up to  $32^{\circ}$  in 25 seconds. Then the ice will begin to melt, and the mingled ice and water will for 142 seconds cease to get warmer, all the heat being expended in melting not in warming the ice ; for at the end of the 142 seconds, that is after receiving 142 heat units, the ice will have been changed into water just as cold as the ice was when it began to melt. The amount of heat consumed in melting without warming one pound of ice is called the latent heat of one pound of water. If the same amount of heat has been employed in raising

the temperature of an equal weight of water it would have increased its temperature by  $142^{\circ}$ ; this is what is meant by saying that the latent heat of water is  $142^{\circ}$ .

As soon as the ice is all melted, the temperature will again begin to rise, the supply of heat remaining constant, at the rate of  $1^{\circ}$  per second; and in three minutes from the melting of the last particle of ice, the water will have reached the boiling point,  $212^{\circ}$ . Steam will then form and escape in bubbles, and the water will cease to grow hotter. For 966 seconds the ebullition will continue without increase of temperature, and at the end of that time the last drop of water will have disappeared in steam. The amount of heat, 966 heat units, which was expended in changing one pound of water into steam, without increasing the temperature, is called the latent heat of one pound of steam. The fact just stated is often thus expressed, the latent heat of steam is  $966^{\circ}$ . This statement is exact only when the steam or vapour of water has been formed at a temperature of  $212^{\circ}$ . At lower temperatures the latent heat of vapour is somewhat greater. It will be observed that the total amount of heat consumed in raising one pound of water from the freezing to the boiling point, and then boiling it away was  $180 + 966 = 1,146$  heat units. If the water had been raised to the temperature of  $60^{\circ}$  only and then allowed to evaporate slowly, until it had wholly disappeared in the air, the total of heat units thus used would have been 1,100, something less than in the former case. But for practical purposes it is sufficiently near the truth to say that the amount of heat required to heat one pound of water at  $32^{\circ}$  F. to a moderate temperature and then to evaporate it at

that temperature is 1,125 heat units, being 1,091 at the freezing point and 1,146 at the boiling point. Hence, if a pound of water be evaporated from wet clothes on a line, or from the surface of wet land on a windy day, or from the damp clothing of one who has been walking in the rain, as much heat must be abstracted from the air and from surrounding bodies as would suffice to raise 45 lbs. of water  $25^{\circ}$  in temperature.

All the statements made above respecting a mass of ice which first becomes less cold, then melts, again grows warmer, and finally boils away, may be read conversely. That is to say, one pound of steam at  $212^{\circ}$ , in condensing to hot water at the same temperature, liberates 966 heat units which are absorbed by surrounding objects, and raise their temperature proportionately. Then the condensed water as it cools, gives up one heat unit for every degree of fall in temperature till  $32^{\circ}$  is reached. Then if the abstraction of heat still continues, the water begins to freeze, parting with heat, yet getting no colder, until it has evolved 142 heat units, by which time it has become a solid mass of ice at  $32^{\circ}$ . After it is frozen, it yields up one heat unit for every two degrees of fall in temperature.

#### *Examples and Experiment.*

68. In a cold room four gallons of water at  $60^{\circ}$  lose one heat unit per second; what weight of ice will have formed in an hour?

69. One pound of steam is condensed by ten lbs. of ice-cold water; what is the resulting temperature?

70. A mass of dry earth, of which the specific heat is one-fifteenth that of water, and which weighs 30 lbs., is moistened with 5 lbs. of water, and, being at a temperature of  $60^{\circ}$ , is exposed to cold in such

circumstances that it loses one heat unit a second. When will the mass begin to freeze, and when will it be completely frozen?

71. The specific heat of a sample of sand is one-fifth that of water; 10 lbs. of it are moistened by 2 lbs. of water, frozen hard, and cooled down to  $10^{\circ}$  below zero. It is placed where it will gain 20 heat units per minute; how long before the mass will be quite dry at a temperature of  $212^{\circ}$ ?

N.B.—Reckon that each pound of water dried away after the ice is thawed costs 1,125 heat units.

Remark that in a still, cold room water will sink considerably below the freezing point without freezing; but, if agitated, will then form as much ice as will give out enough latent heat to raise the temperature of the whole to  $32^{\circ}$ .

72. A pound of water has sunk to the temperature of  $20^{\circ}$  without freezing; how much ice will form, if it be shaken?

73. One cubic foot of a certain soil, when dry, weighed 80 lbs. and had a specific heat  $\frac{1}{4}$  that of water. Having been saturated with 40 lbs. of water, its temperature one morning was found to be  $35^{\circ}$ . It was exposed to the sun so that it received 10,700 heat units in the day. Under the influence of the wind it lost 9 lbs. of water by evaporation during the day. What was its temperature at the close of the day?

74. Other things being as in the last example, what would the temperature of the soil have been, if it had contained only 30 lbs. of water, and had lost only 8 lbs. by evaporation?

From the results of the two preceding examples it is evident that, although water is essential to the growth of plants, its presence in too great quantity



is injurious to those which are usually cultivated. Too much moisture makes a soil cold.

Exp. 21. Put one ounce of ice into three ounces of boiling water and observe the temperature just as the ice is melted; compare with the results of calculation. Try with different amounts of ice and of water at different temperatures.

### § 6. *Dew, Rain and Snow.*

The evaporation of water, however, like every other natural process, is of the highest utility. To it we owe the refreshing dew and fertilizing rain, and the kind covering of snow which protects our fields from the intensity of the frosts in winter. Its relations to plants are so important and so beautifully adapted to the purposes which they serve, that no apology will be necessary for devoting a little time to their consideration.

It was before stated that heat is necessary for the evaporation of water,—and when this heat is removed from the invisible vapour thus produced, it is again reduced to the state of water. Thus, if in summer a pitcher of cold water be placed upon a table, in a short time the outside of the vessel becomes moist or covered with globules of water. This shows that the air always contains the vapour of water, and that this vapour, when it touches a cold body, is reduced to the liquid state. These simple facts will enable us to understand the general causes of *dew and rain*.

In clear weather, the earth's surface and the air in contact with it, are warmed by the rays of the sun. But every warm body has a tendency to radiate or send forth its heat, until it becomes as cold as the surrounding objects. After sunset, therefore, the earth's

surface rapidly cools, until, at length, it becomes so cold that the vapour of the air in contact with it, becomes condensed in the form of *dew*, or if the cold be more intense, in that of hoar frost. But different substances, when allowed to cool, lose their heat with different degrees of rapidity; and of course, those which cool most quickly and thoroughly, must collect the greatest quantity of water from the air. This property also forms the basis of an arrangement beneficial to vegetation; for grass and other herbage radiate their heat more rapidly than most other bodies; and hence, "in the cool of a summer's evening, the grass plat is wet when the gravel walk is dry; and the thirsty pasture and every green leaf are drinking in the descending moisture, while the naked land and the barren highway are unconscious of its fall."

When the sky is covered with clouds, these return the heat which the ground loses by radiation; and when the air is agitated by the wind, its vapour is usually insufficiently cooled for condensation, hence in cloudy and windy nights, there is no dew.

The early frosts of autumn depend on causes similar to those of dew. In autumn, plants are cooled to a temperature below the freezing point, by the radiation which takes place during a clear night; in such cases, a very slight covering, even a thin cloth, may impede radiation, and save a plant; and exposure to a slight current of air, or even facing a cloudy spot of the sky, or smoke in the air, may save particular parts of a field.

Other causes may condense vapour at various heights in the air. Moist and warm air ascending from the earth's surface, and entering cooler regions, will begin to relinquish the moisture which it contains;

and a cloud will be formed which may either descend in rain, or be wafted to some distant locality. The more usual explanation of the formation of clouds is founded on the fact, that if two equal portions of air differently heated, and both containing as much vapour as they can retain, are mixed, the temperature of the mixture will be the mean of that of the two portions of air ; but this intermediate temperature will not be sufficient to maintain, in the state of vapour, all the water of both portions, and consequently water must be deposited. When therefore, in our atmosphere, a current of warm air becomes intermixed with one that is colder, a quantity of fog, mist, or cloud is produced, proportioned to the excess of the watery vapour contained in both currents, above the quantity which they can retain when mixed. Lastly, electricity, whose agency is so manifest in thunder storms, acts, in ways not yet well understood, in accumulating clouds, and precipitating their contents to the earth in the form of rain, or, more rarely, as destructive showers of hail.

The subjoined table gives the weight of water contained as invisible vapour in every cubic foot of air saturated at each of the temperatures mentioned :

Grains.		Grains.		Grains.		Grains.	
20°.....	1.5	45°.....	3.2	70°.....	8.3	95°.....	18.0
25°.....	1.6	50°.....	3.9	75°.....	9.9	100°.....	20.5
30°.....	1.8	55°.....	4.7	80°.....	11.6	105°.....	23.0
35°.....	2.1	60°.....	5.8	85°.....	13.5	110°.....	26.4
40°.....	2.6	65°.....	7.0	90°.....	15.6	115°.....	30.5

### *Examples.*

75. How many tons of water are contained in a cubic mile of saturated air at 70° ?

76. How many tons of water in a cubic mile of saturated air at 30° ?

77. How many tons of water in two cubic miles of saturated air at  $50^{\circ}$ ?

Remark that for the purpose of the next question we may reckon that if equal quantities of air at different temperatures be mingled the mixture will be of the average temperature.

+ 78. How many tons of water would be deposited as rain if a cubic mile of saturated air at a temperature of  $70^{\circ}$  were mixed with one cubic mile of saturated air at  $30^{\circ}$ ?

Air is seldom saturated with vapour, but the actual amount present at any time may be easily determined by observing at what temperature moisture begins to be deposited from it. For the air is saturated at that temperature. The temperature at which moisture begins to be deposited is called the dew-point.

*Examples and Experiment.*

79. On a hot day, temperature  $90^{\circ}$  in the shade, a glass jug of well-water at a temperature of  $50^{\circ}$  was just dimmed by the deposit of moisture on the outside. At that time how many grains of water were there present in one cubic foot of air? What per cent. of the moisture necessary to saturation was present? What per cent. of the weight of the air was moisture, the barometric pressure being 30 inches?

80. At 8 o'clock in the evening the temperature of a grass plat and of the air above it is  $65^{\circ}$ ; the temperature of the grass continues to fall at the rate of  $1^{\circ}$  every 15 minutes until four o'clock in the morning, when it ceases to fall. The air contains 2.6 grains of moisture per cubic foot. At what time will dew begin

to form? Will there be hoar frost? What will be the lowest temperature of the night?

81. The temperature is  $75^{\circ}$  and the dew-point  $5^{\circ}$  lower; what per cent. of the moisture necessary to saturation is present, and what per cent. of the moisture present would be deposited if the temperature were to fall  $20^{\circ}$ ?

Exp. 22. Hang up a tin of very cold water in a room on a hot day. Take the temperature of the room, and also of the water when the moisture at first condensed on the outside disappears. From the data so obtained calculate the amount of moisture present in each cubic foot of air in the room and the additional amount which it is capable of absorbing.

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## CHAPTER III.

### CHEMICAL PRINCIPLES.

#### § 1. *Laws of Combination.*

Instead of explaining the general principles of chemistry in a formal manner, we shall illustrate them by a familiar example. If we take 100 pounds of pure limestone, and expose it for some time to a red heat, as is done in lime-kilns, an invisible air or gas escapes from it, and at length we have only 56 pounds of quick lime remaining. If we have collected the gas which has been given out, its weight will be found to be 44 pounds, or as much as the limestone has lost. This gas is known to chemists as carbon dioxide. Limestone therefore is a *compound* substance, and may be *decomposed* or separated into two other substances. But this process may be carried still farther. The skilful chemist can obtain from the 44 pounds of carbon dioxide, 12 pounds of carbon or charcoal, and 32 pounds of a gas named oxygen; and from the 56 pounds of quick lime, called by the chemist calcium oxide, 16 pounds of oxygen and 40 of a metal named calcium. Here then we have:

12 Carbon	and	32 Oxygen,	forming	44 Carbon Dioxide
40 Calcium	"	16 Oxygen,	"	56 Calcium Oxide

Forming, when united.....	100	Limestone or Calcium Carbonate.
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#### *Experiment.*

Exp. 23. Weigh a fragment of limestone as big as a pea; heat it on charcoal before the blowpipe with a

gentle blast till it has been red hot for half a minute. (See exp. 32.) Weigh again when cold, and see what proportion of the weight has been lost. Compare with the foregoing statements.

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First, it is evident that such a union is not a mere mixture of carbon, calcium and oxygen; it is that more intimate union termed *Combination*, and we see that *when two bodies thus combine, the result is a third substance very different from either.*

Secondly. If we take any number of specimens of *pure* limestone we shall find them all to consist of the same substances, and in the same proportion; or if we form carbon dioxide or lime by causing their ingredients to unite, it will be found that weights of these corresponding to those which are found in limestone, are alone capable of combining to form these substances. These ingredients, therefore, *combine in uniform and definite proportions.*

#### *Experiment.*

Exp. 24. Try experiment 23 with several different bits of limestone and of marble.

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Thirdly. If we put some pounded limestone into a glass, and pour upon it a little hydrochloric acid, an *effervescence* or boiling up will take place, in consequence of the carbon dioxide of the limestone escaping; and, after this has subsided, we shall find that the hydrochloric acid has combined with the lime, forming calcium chloride. In this case, then, the hydrochloric acid has expelled the carbon dioxide in order that it might itself combine with lime. *The*

*tendencies of bodies to combine with each other, then, are not equally powerful, so that previously existing combinations may be decomposed by the addition of new substances.*

*Experiment.*

Exp. 25. Weigh a bit of limestone as big as a pea. Then weigh a test tube with half a teaspoonful of hydrochloric acid in it, put the limestone into the hydrochloric acid, and, sometime after it is dissolved weigh again. What has become of the lost weight? How does the proportion of lost weight compare with the proportion lost in experiment 23?

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Fourthly. After having decomposed limestone, and obtained carbon, calcium, and oxygen separately, we cannot decompose these three substances, or separate anything further from them; they are therefore termed *simple* or *elementary* bodies.

Fifthly. It is found that these principles apply to nearly all the objects known to us; that these are, like limestone, compound bodies, and that they are all composed of a limited number of simple substances, or elements, which may be arranged as follows:

6 *Gases*—Oxygen, Hydrogen, Nitrogen, Argon,\* Chlorine, Fluorine.

10 *Nonmetallic liquids or solids at common temperatures*—Sulphur, Selenium, Phosphorus, Bromine, Iodine, Carbon, Boron, Silicon, Arsenic, Tellurium.

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\*Argon is a recently discovered constituent of the atmosphere, present in small quantity and having no known relations to animal or to vegetable life. It is, therefore, not referred to again in this work.



46 or more *Metals*.—Potassium, Sodium, Magnesium, Aluminum, Calcium, Manganese, Lead, Iron, Copper, &c.

Some of these simple substances are familiarly known in an uncombined state, for example sulphur and copper; but the greater number are found in nature only in different forms of combination.

## § 2. *The Aim of the Chemist.*

It is the business of chemistry to *analyze* compounds, that is to separate their constituent elements, determining the proportions of these by weight; by *synthesis* to reproduce known combinations or to form new ones; and to ascertain the properties of substances, whether elementary or compound. It further applies the knowledge thus obtained to the explanation of all chemical processes whether in nature or in the arts.

## § 3. *Chemical Symbols and their Connotation.*

Chemists have adopted a system of symbols which is of the greatest possible convenience for the concise statement of many chemical truths. It rests upon the fundamental conception that each simple body is made up of inconceivably minute particles, called atoms, which we have no means of subdividing, and which are probably in all respects alike in each simple substance, especially being equal to each other in weight. Although the atoms composing any one simple substance are supposed to be alike, those of different simple substances are supposed to differ in various particulars and especially in weight.

The several chemical atoms are symbolized by letters, which are usually the initial letters of the Latin

names of the substances. So the three simple substances which constitute lime-stone are thus represented:—One atom of carbon by C, one of calcium by Ca and one of oxygen by O. Further, as the weights of these atoms are supposed to be quite definite, C stands for an invariable though exceedingly minute weight of carbon. Similarly, Ca and O stand for different though quite definite weights of calcium and of oxygen respectively. No one knows with any approach to accuracy just what the weight of any atom is as compared with our ordinary weights like the grain or the pound. But chemists have good grounds for affirming that the relative weights of the atoms of different elementary substances are known, and this with great exactness. When compared with one atom of hydrogen, the lightest substance known, one atom of carbon weighs 12 times as much, one of calcium 40 times as much and one of oxygen 16 times as much. It is, therefore, customary to represent the weight of one atom of hydrogen, H, by 1, making it the standard of comparison, and to say that the weight of one atom of C is 12, of Ca 40, and of O 16. These numbers are called the atomic weights of hydrogen, carbon, calcium and oxygen respectively.

Each compound body again is supposed to be made up of molecules, that is of small definite groups of atoms, each molecule being like every other in the compound, being made up of the same number of atoms similarly arranged, and having, therefore, the same aggregate weight. The chemist's view of the molecular constitution of compound bodies is indicated by formulæ in which are combined the symbols of their elements. So he represents carbon dioxide by  $\text{CO}_2$ , meaning to indicate thereby that each

molecule of carbon dioxide is composed of one atom of carbon united to two atoms of oxygen; representing also thereby the fact that carbon dioxide is composed of carbon and oxygen united in the proportions of 12 parts by weight of carbon to twice 16, that is 32, parts of oxygen. It will be readily seen that  $\text{CaO}$ , the formula for quick lime, called by the chemist calcium oxide, represents that this substance is made up of 40 parts of calcium united to 16 parts of oxygen. The chemist represents limestone, which he names calcium carbonate, by  $\text{CO}_2 + \text{CaO}$ , or, combining the two expressions together, by  $\text{CaCO}_3$ . He thus expresses briefly the fact that calcium carbonate consists of 40 parts calcium, 12 parts carbon and 48 parts oxygen combined together.

### *Examples.*

82. In one pound of carbon dioxide what is the weight of C, and what of O?

83. In one long ton of lime,  $\text{CaO}$ , how much of each ingredient?

N.B. The long ton weighs 2,240 lbs.

84. In 25 lbs. of pure calcium carbonate,  $\text{CaCO}_3$ , how much calcium, carbon and oxygen are there?

85. What is the composition of 88 lbs. carbon dioxide,  $\text{CO}_2$ ?

86. In a charcoal fire carbon dioxide is formed by the union of the charcoal, carbon, with oxygen from the air; how many lbs. of oxygen would be needed to burn up a pound and a-half of charcoal? and how much carbon dioxide would be formed?

87. Hydrogen in burning unites with the oxygen of the air to form vapour of water. The formula of water is  $\text{H}_2\text{O}$ . When one pound of hydrogen is

burned, with how much oxygen does it unite, and how much water is formed?

88. What is the weight of each ingredient in 75 lbs. of white marble, pure calcium carbonate?

89. There are 20% of impurities in a piece of limestone weighing 375 lbs.; how much carbon dioxide, and how much calcium are there in it?

90. When charcoal burns with an insufficient supply of oxygen, a gas named carbon monoxide, of which the formula is  $\text{CO}$ , is formed; how much C, and how much O are there in 112 lbs. of it?

91. Carbon monoxide will burn: it may be sometimes seen burning with a flickering blue flame on the top of a coal fire. In burning it unites with O to form  $\text{CO}_2$ . What weight of O is required to consume 14 lbs. of CO, and what weight of  $\text{CO}_2$  is formed?

92. In the processes of digestion and respiration of an animal one ounce of glucose,  $\text{C}_6\text{H}_{12}\text{O}_6$ , is made to unite with O so as to produce carbon dioxide and water. How much oxygen, in addition to that which the glucose already contains, will be required, and how much carbon dioxide and water will be formed?

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The whole significance of these symbols and formulæ cannot here be shown; but one point more must be mentioned. It is held that each molecule of matter in the gaseous state occupies the same space as any other molecule of gas of whatever kind, under the same conditions of temperature and pressure. It follows that under the same conditions equal volumes of different substances when in the gaseous form contain the same number of molecules. For example, at a temperature of  $60^\circ$ , and under a barometric pressure of 30 inches one pint of one gas contains the same

number of molecules as one pint of any other gas. To make this statement accordant with all observed facts, in relation to both simple and compound gases, it is necessary to assume that simple gases are made up, not of separated atoms, but of molecules that consist of atoms joined usually in pairs. Thus if a mass of carbon dioxide be made up of molecules, each represented by the formula  $\text{CO}_2$ , an equal bulk of oxygen must be considered to be made up of the very same number of molecules, each represented by  $\text{O}_2$ , and an equal bulk of hydrogen to be made up of the same number of the molecules  $\text{H}_2$ .

These considerations enable us to calculate the relative weights of equal volumes of gases from the chemical symbols of the gases. If a pint of oxygen contains as many molecules as a pint of hydrogen, it is clear that the pint of oxygen weighs as many times the pint of hydrogen as the molecule of oxygen does the molecule of hydrogen. The molecule of oxygen,  $\text{O}_2$ , weighs twice 16, because it is made up of two atoms of oxygen each weighing 16. In like manner the molecule of hydrogen,  $\text{H}_2$ , weighs twice 1. So the molecule of oxygen weighs 16 times as much as the molecule of hydrogen, and, consequently, the pint of oxygen weighs 16 times as much as the pint of hydrogen. One illustration more will suffice. The molecule of carbon dioxide is represented, as was before said, by  $\text{CO}_2$ ; its weight, therefore, is  $12 + 2 \times 16 = 44$ . Therefore the weight of the molecule of carbon dioxide is 22 times that of the molecule of hydrogen, and that of a pint of  $\text{CO}_2$  is 22 times that of a pint of hydrogen. To sum up—the weight of the molecule of carbon dioxide is 44, that of oxygen is 32, and that of hydrogen is 2; therefore the weight of a

volume of carbon dioxide is 22 times, and that of the same volume of oxygen is 16 times that of an equal volume of hydrogen, the pressures and temperatures being also equal. Remember that the specific gravity of hydrogen is .0693. (See page 16.)

*Examples.*

93. What at  $60^{\circ}$  and barometric pressure 30 inches is the weight of one cubic foot of hydrogen? (See page 16.)

94. If the weight of a certain volume of hydrogen, be one ounce, what in the same circumstances would be the weight of an equal volume of each of the following gases,—oxygen, carbon monoxide and carbon dioxide?

95. What is the weight of one imperial gallon of each of the following gases,—H, O, CO, CO<sub>2</sub>, at the freezing point, when the barometric pressure is 29.4 inches? (See page 25.)

96. The barometric pressure being 30 inches and the temperature  $60^{\circ}$ , what would be the weight in pounds of a room full of CO<sub>2</sub>, the room being 14 feet long, 10 feet broad and 9 feet high?

97. In the same circumstances as in the preceding example, what is the weight of air in a room 34 feet by 21 feet by 15 feet?

§ 4. *Acids, Alkalies, Salts.*

Acids have a sour taste, redden blue litmus paper and vegetable blues generally. Alkalies are highly soluble in water, have a caustic and soapy taste, combine with acids to form salts, and with fats to form soaps; change vegetable red to blue, and yellow to brown; and tend, when strong and pure, to corrode

animal and vegetable substances. Salts are produced by the action of acids and alkalies on each other; they have a peculiar taste, which is known as saline, and they do not affect vegetable colours.

For example, vinegar is an acid, it tastes sour, and we all know that it turns the dull purple of red cabbage bright red when pickled. Caustic soda, sodium hydroxide, is an alkali, and has a burning, acrid taste; a scarlet geranium immersed in a solution of caustic soda will slowly turn blue, the change taking place quickly, if the flower be first crushed in the fingers; caustic soda also turns the yellow mustard of the shops or the crushed flower of a buttercup dark brown. But if into a solution of caustic soda a sufficient and not excessive quantity of vinegar be poured, both the caustic taste of the soda and the acidity of the vinegar will disappear, and be replaced by a saline taste; and the resulting solution will have no effect upon vegetable colours. Alkalies and all substances which unite with acids so as to neutralize their acid properties, and to form salts by combination with them, are called bases. Many of them being but slightly or not at all soluble in water, do not exhibit such causticity, nor so strong an action on vegetable colours as the alkalies, these properties being almost proportional to solubility.

### *Experiments.*

Exp. 26. Dissolve in separate tablespoonfuls of water a fragment of sodium hydroxide, a bit of calcium oxide, each as large as a grain of wheat, and a drop of ammonia. Dip a clean pen in each and write on reddened litmus paper. Put a bit of red



litmus paper into each. Try the effect of each on the crushed petals of red flowers, and of yellow flowers.

Exp. 27. Into separate tablespoonfuls of water drop one drop of sulphuric acid, one of hydrochloric acid, two of vinegar. Write with the solutions on blue litmus paper. Put a bit of blue litmus paper into each. Try the effect of each on the crushed petals of blue flowers.

Exp. 28. Collect your acid liquids together in one glass, and drop your alkaline liquids in cautiously until the resulting mixture will neither turn blue litmus red, nor red litmus blue. Then the acids and alkalies will have neutralized each other, and the solution is said to be neutral.



## CHAPTER IV.

### CHEMICAL PROCESSES.

#### § 1. *Tests and Testing.*

A most important practical question for chemists is this: How shall we recognize with certainty the various substances, simple or compound, with which we deal?

It is of course easy to recognize by their physical properties many elementary substances. Quicksilver cannot be confused with anything else. But it is not equally easy to distinguish many substances from one another, especially when present in small quantities and largely admixed with other substances, or combined with them.

Chemists have noted a large number of peculiar phenomena which, under certain conditions, show the presence of particular substances. When they seek to determine the presence of some substance, they reproduce the conditions under which the peculiar phenomena should result if the substance sought were present; and, as these phenomena appear, or do not appear, the presence or absence of that particular substance is demonstrated. This process is called *testing*; and, inasmuch as the testing usually depends on bringing two chemical substances together which forthwith produce some notable appearance, each substance is said to be a *test* of the other. Substances thus used as tests receive the common name of reagents.

Some of the tests used by the chemist are general, serving to indicate classes of substances. Thus a solution of blue litmus is a sensitive test for acids, which in very small quantity turn it red; and reddened litmus is a test for alkalies which change it back to blue. See Exps. 26 and 27.

### *Experiments.*

Exp. 29. Into a test tube put a bit of iodine as large as a pin's head and warm the tube over a spirit lamp. Smell cautiously.

The appearance of this beautiful purple vapour proves the presence of iodine. No other substance presents such an appearance. No other substance smells quite like iodine. The appearance and the smell are tests of iodine; by these properties the chemist recognizes it. But these properties are not always available; iodine in solution gives no purple vapour; iodine in combination has no characteristic smell. And these tests are not sensitive; for exceedingly small quantities of iodine cannot be thus discovered.

Exp. 30. Smear a piece of paper with starch paste and dry it. Put a drop of water on the starchy side of the paper and into the water a bit of potassium iodide as large as a pin's head. Near the water draw a line of nitric acid like a pen stroke, and run the drop of water into the nitric acid. Observe the coloration.

No substance but iodine colours starch in this way. Iodine and starch are tests for each other; they are used by the chemist as reagents; they are very sensitive tests each for the other; they can be used when the iodine is in solution; and, with the help of a little nitric acid, when the iodine is combined with a metal.

Exp. 31. Dissolve a bit of alum as large as a grain of wheat in a teaspoonful of water. Divide the solution into two parts. Into one part drop one drop of ammonia; into the other one drop of solution of barium nitrate, and a minute later one drop of nitric acid.

The white gelatinous precipitate formed in the first solution shows the presence of alumina; and the white cloud insoluble in nitric acid, which is formed in the other case, demonstrates the presence of sulphuric acid.

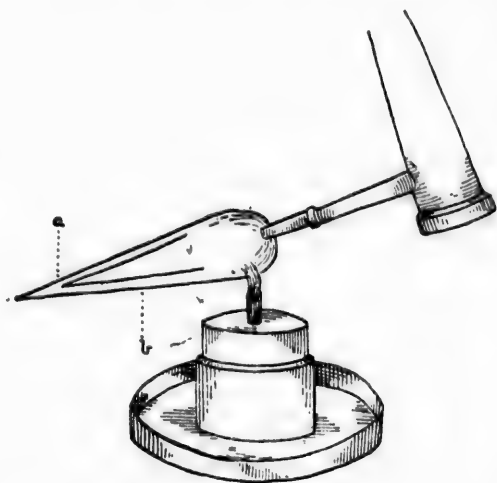


Fig. 2.

Exp 32. With a blow-pipe maintain a steady, well-defined flame from an oil(not coal oil)lamp. To learn to do this, 1st, keep the cheeks distended while breathing through the nose; 2nd, with the blow-pipe between the lips do the same thing, but, as the air will escape from the blow-pipe, the mouth must be from time to time refilled from the lungs, without interruption to

the stream of air through the blow-pipe; 3rd, direct the blast into the flame of the lamp, or into a candle flame, and keep the flame steady in form and size. Try to get a sharp point of flame directed downward with an inner luminous cone. The point of this cone is called the reducing flame, (*b*), and the outer scarcely visible flame is called the oxidizing flame, (*a*).

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Exp. 33. At the end of a thin copper wire, four inches long, make a loop about  $\frac{1}{8}$  in. in diameter; heat it red hot in the oxidizing flame, put on it a bit of microcosmic salt as large as a grain of wheat, and boil all moisture away in the blow-pipe flame; then dip the glassy bead of salt while still hot into some finely powdered common salt and once more heat in the oxidizing flame. The magnificent blue colour produced is characteristic of copper chloride, and in the present instance demonstrates the presence of chlorine in the common salt.

Other examples of tests and testing will be found in the next chapter.

## § 2. *Separation of mixtures.*

In all the experiments that follow weigh carefully the substances operated upon and the results of the operations, when possible. Before weighing, thoroughly dry the substances to be weighed, if they are at all damp, by exposing them for some time to the temperature of boiling water. Compare the weights of the quantities of matter operated on, and of the resulting quantities and endeavour to account for all the matter employed, avoiding loss. Use the smallest quantities of the materials employed that will enable the results to be clearly noted.

### *Experiments.*

Exp. 34. Mix fine sand and sawdust; divide into halves; separate half of the mixture by *winnowing*, and the other half by shaking up in water and skimming off the sawdust, that is by floatation.

Grain and chaff are separated by *winnowing*.

Exp. 35. Mix iron filings and sand. Put a teaspoonful of the mixture in a heap at one side of a dinner plate; pour enough water into the plate to be one-eighth of an inch deep, and by rolling the plate gently make a current of water sweep over the mixture; try to wash away the sand from the filings.

Gold dust is separated from sand by *washing*; for a gentle current of water will sweep away the lighter grains of sand and leave behind the heavier grains of gold. In much the same way the wash of waves, currents and tides carries the finer particles of the shore out to sea, and deposits them in beds of clay, while sands are deposited nearer the shore and boulders and pebbles constitute the shore itself.

Exp. 36. Mix half a teaspoonful of salt with ten times its bulk of sand and divide into equal portions; put one-half into a test tube with water and shake for some time; then pour off the brine and repeat the process; put the remaining half into a tube open at both ends and stand on a board; let water drop gently in on the top of the mixture; brine at first strong, but becoming weaker and weaker will ooze out under the bottom of the tube and may be caught; clean sand will be left behind; see in which way you can best clean the sand, and in which way you can most perfectly collect the salt, which may be recovered from the brine by boiling the water away. The chemist calls the second process *lixiviation*; the farmer calls it leaching. So he leaches ashes in making potash, and the rains leach a heap of manure when they soak out and wash away its soluble and most valuable ingredients.

Exp. 37. Divide a spoonful of tea into three equal parts; steep one part in water for a day; pour hot

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water on another part, and let it stand a few minutes ;  
boil the remaining part in water for a minute or two.  
Observe the differences in appearance and taste of the  
three liquids when poured off the tea.

The first mode of dealing with the tea is called  
*digestion*, the second *infusion*, and the third *decoction*.  
If digestion is prolonged until decay begins, the pro-  
cess is called *maceration*.

Exp. 38 At a gentle heat melt a little lard in a  
teaspoon. Let it cool slowly, and just as it looks opaque  
put a drop of it on some blotting paper that has been  
blackened with ink and dried. The lard will be  
divided into two parts, a more easily fusible fat or oil,  
lard oil, which will spread in a greasy blotch into the  
blotting paper, and a more solid fat, stearine, which  
will remain at the middle of the circle of grease.

The stearine and the lard oil are separated by differ-  
ence of fusibility. This method of separation is used  
on a large scale in the manufacture of lard oil ; melted  
lard is allowed to cool to about 100°F. At this temper-  
ature stearine solidifies in small particles disseminated  
through the more liquid portions of the fat, and when  
the pasty mass is enveloped in cloths and subjected to  
pressure, the oil is squeezed out and the less fusible  
stearine is retained in the cloths.

Exp. 39. Mix a bit of iodine as large as a grain of  
wheat with half a teaspoonful of sand in a long test  
tube ; heat the mixture over a spirit lamp.

The sand and the iodine will be separated by *sub-  
limation* of the iodine. In a similar way camphor is  
separated from the wood of the camphor tree, and  
native sulphur is separated from the earthy matters  
with which it is mixed.

Exp. 40. Fold a circle of filter paper, blotting paper, into a quadrant: open it out into a cone so as to leave three thicknesses of paper on one side and one on the other side; fit it into a glass funnel, wet it with a little clean water; pour muddy water into the filter, taking care that the water does not rise above the edge of the filter paper. The clear water that drops through is called the filtrate; you have *filtered* the water.



Fig. 3.

Exp. 41. Stir up a little clay in water. Let it stand aside, and when it has settled pour off the water to the last drop without disturbing the sediment. This is *decantation*.

Exp. 42. Repeat Exp. 13, and see what proportion of the alum you recover by *crystallization*.

Exp. 43. Boil away the water from which you have removed the crystals or alum in the foregoing experiment, and weigh the residue. See if you have recovered the whole of the alum by the *evaporation* of the water.

Exp. 44. Fill a test tube one-third full of water, colored red with dye, and one third full of sweet oil. Shake them well together. The opaque pink liquid produced is called an emulsion. Let the tube stand till the contents have again separated and decant the olive oil.

Exp. 45. Make a similar emulsion, and pour it into a filter wet with water. Thus liquids which do not



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mix may be separated by decantation or by filtration.

Exp. 46. Half fill a test tube four inches long with beer. Cork the tube with a cork that has a long tube

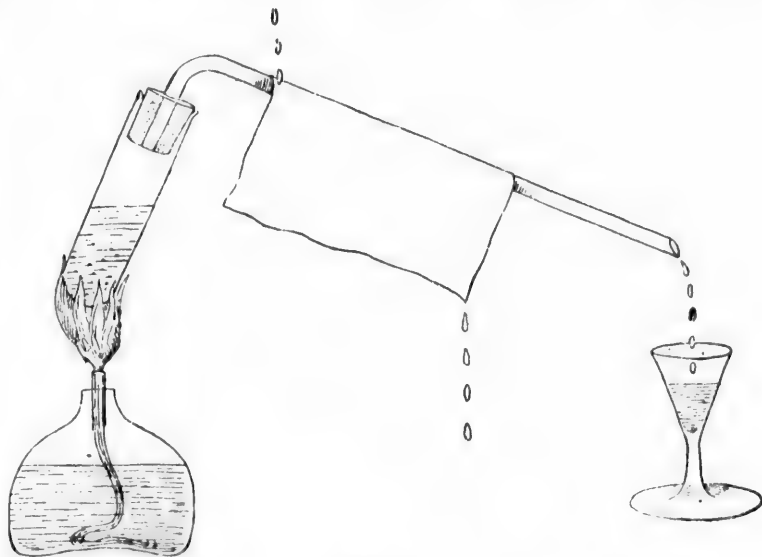


Fig. 4.

through it bent nearly at right angles. Set the test tube over a spirit lamp so that the exit tube may slant slightly downward to a glass. Lay wet blotting paper on the exit tube and keep it wet so as to cool the tube. Presently a colorless liquid will drip into the glass. When a few drops are collected, smell it; set it on fire; it is alcohol.

The boiling point of water is  $212^{\circ}$ , that of alcohol is  $173^{\circ}$ . Liquids whose boiling points differ considerably may be separated by *distillation*.

Exp. 47. Collect a bottle full of carbon dioxide as in experiment 71. Pour into it, in a cool place, a little water and shake well, covering the mouth of



the bottle with your thumb. Repeat the process until the bottle is half full of water. Divide the water, saturated with gas, into equal parts in two glasses. Put one in a warm place, put the other into the gem jar of experiment one, and suck air out of the jar. Observe the formation of bubbles in each case. The bubbles are bubbles of carbon dioxide.

Gas may be removed from liquids in which they are dissolved by heating the liquid or by diminishing the pressure on the surface.

Exp. 48. Having prepared some chlorine, as in Exp. 68, pour some into a bottle by the aid of a funnel until the bottle is half full; then pour in half as much water and immediately close the mouth with your thumb and shake the bottle. Why is your thumb sucked into the bottle?

Exp. 49. Half fill a bottle with chlorine. Cover the mouth with your thumb. Invert the bottle; dip the mouth under water and remove your thumb; soon the chlorine will be absorbed by the water and the air in the bottle will remain. Gases may be separated from one another by means of the greater solubility in some liquid of one ingredient of the mixture.

### § 3. *Analysis of Compounds.*

All the separations considered in the preceding section have been merely mechanical and physical. No permanent change of properties of the substances operated upon has been produced. In Exp. 36, for example, the sand and salt operated on remain sand and salt throughout the operation. But in Exp. 23 the heated calcium carbonate breaks up into two distinct substances, calcium oxide and carbon

dioxide differing materially in their properties from the calcium carbonate from which they were derived. The calcium carbonate is in this case *decomposed* by the heat, and if we carefully weighed the original substance and collected and weighed the results of the operation, so as to be sure that we had lost nothing, we should say that we had analysed the calcium carbonate.

One or more ingredients of a mixture may often be removed by chemical means.

### *Experiments.*

Exp. 50. Mix some filings of zinc and copper and pour sulphuric acid, diluted with ten times its bulk of water, on them; observe that the zinc is dissolved and that the copper remains undissolved.

N.B.—In diluting the acid drop the acid slowly into the water.

Exp. 51. Observe the effect of pouring dilute sulphuric acid on brass filings.

Exp. 52. Put two drops of sulphuric acid in a wine glass of water. Observe its sour taste and its action on blue litmus paper. Put into it a half teaspoonful of litharge and shake well. Let it settle and again taste it, and try it with blue litmus paper.

Exp. 53. Seal up a stick of phosphorus in the gem jar of experiment 1, having a piece of rubber tube slipped over the glass tube that passes through the stopper; let the free end of the rubber tube dip into a pail of water and set the whole aside to stand for 24 hours. Observe with great care what has taken place, for the results are very important. Was there any water in the jar when it was first sealed up? How much is in it now? Is the jar one-fifth full of

water? Without much disturbing the jar unseal it, quietly remove the stick of phosphorus and drop it into water. Now lower a burning taper into the air in the jar. Why does it go out? Would it go out as quickly if lowered into a jar full of ordinary air? Why is the air in the jar different from ordinary air? What has become of the air that has gone from the jar, the place of which was supplied by water.

The answers to these questions are that air is a mixture of two gases, very distinct in properties, one of which is removed by the action of the phosphorus, and the other of which is not. The part removed by the phosphorus is the part of the air which supports combustion; it amounts to about one-fifth of the volume of the air and is called oxygen. The part which is not removed by the phosphorus, and which will not support combustion, is called nitrogen. Phosphorus is capable of slowly uniting with the oxygen of the air at a low temperature, to form a compound which readily unites with water and is dissolved in it. The result of the union is an acid, and in consequence the water in the jar reddens blue litmus.

Exp. 54. Into a long test-tube of hard glass put enough red precipitate, mercuric oxide, to rise a quarter of an inch in the tube. Cork the tube with a cork through which passes a long, small tube, open at both ends and bent as in the figure. Let the tube be so supported that the free end of the delivery tube may dip into water under the mouth of an inverted tube filled with water. Then strongly heat the mercuric oxide by a lamp, as in the marginal figure. The red oxide of mercury will blacken and decompose. Mercury will condense on the cooler upper part of the first test tube and bubbles of gas

will be collected in the second test tube. When the action ceases, or when the second test tube is full of

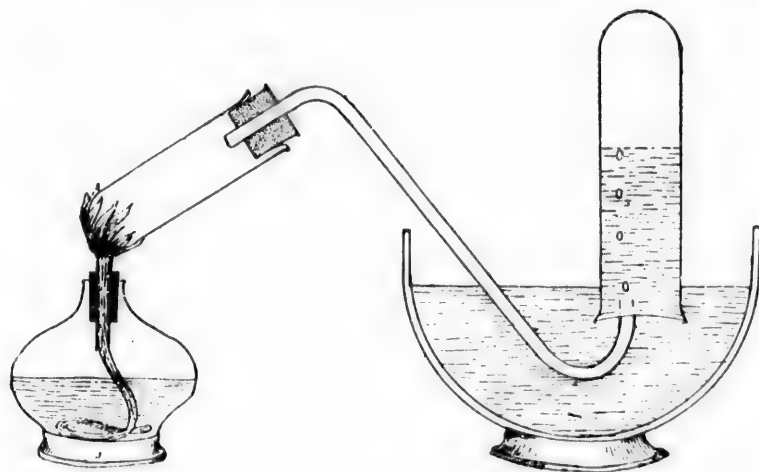


Fig. 5.

gas, this tube may be withdrawn, stopped with the thumb and turned mouth upward. Then a glowing match end inserted into the gas will brighten up and be rekindled.

N.B.—Take care to remove the bent tube from the water before you remove or extinguish the lamp.

The red precipitate,  $\text{Hg O}$ , has been resolved by heat into metallic mercury,  $\text{Hg}$ , and oxygen,  $\text{O}$ . Other decompositions can be similarly effected by the application of heat; and still others are brought about by the passage of currents of electricity, or by the action of light.

#### § 4. *Synthesis, Combination.*

Chemical changes of every kind are greatly facilitated by minute division and close contact of the substances acting on each other. Two masses of sulphur,

S, and of copper, Cu, produce no effect on each other, although permitted to lie in contact with each other for an indefinite time. But if they be reduced to an impalpable powder and ground together in a mortar, they unite into copper sulphide,  $\text{CuS}$ , with the evolution of much heat.

Gases readily mix with each other, but in the gaseous state particles of matter though exceedingly finely divided, do not come into such close contact with each other as in the liquid state. Hence the gaseous condition of matter is not so favourable to chemical reactions as the liquid. But when gases do combine, the combination is frequently effected with suddenly explosive violence.

#### *Experiments.*

Exp. 55. Fill a small rubber bag with a mixture of two volumes of hydrogen and one of oxygen. Affix a nozzle to the bag, and, by squeezing out some of its contents while the nozzle is beneath the surface of some strong soap-suds in a little tin dish, blow up a froth of soap-bubbles. Remove the bag a few feet off, and touch the froth with a lighted match; a violent explosion will ensue as a result of the combination of the oxygen and hydrogen with each other, in accordance with the equation  $2\text{H} + \text{O} = \text{H}_2\text{O}$ , *i. e.*, water.

When gases combine with liquids the union is facilitated by causing a stream of the gas to bubble through the liquid.

Exp. 56. Blow air from the lungs by means of a straw through lime water. The carbon dioxide,  $\text{CO}_2$ , in the air expired, unites with the calcium hydroxide,  $\text{CaO}_2\text{H}_2$ , dissolved in the water, to form a white precipitate which is calcium carbonate  $\text{CaCO}_3$ .

N.B.—Lime water is made by stirring a tablespoonful of quick or slaked lime in a pint of water, letting it settle and then pouring off the clear liquid. It must be kept in a well-corked bottle.

The union of gases with solids is aided by forcing a current of the gas over and between the particles of the solid. So a charcoal fire is kept alight by the draft which causes the oxygen, O, of the air to come in contact with the glowing coals, C, forming  $\text{CO}_2$  by the union.

In most instances of chemical combination heat is generated, as in many of the examples of combination given above. In some instances the application of heat is necessary to initiate chemical combination, and then the act of combination itself supplies enough heat to continue the action. To light a charcoal fire, fire must be applied; but when the action has once begun, it is not necessary to supply extraneous heat in order to maintain it.

#### § 5. *Metathesis, Replacement, Double Decomposition.*

Comparatively few chemical transformations are either mere decompositions or mere combinations. By far the greater number result from *metathesis* which is either the *replacement* of one atom or molecule of a compound by another atom or molecule; or an *interchange* of atoms or molecules between two compounds, where, two compounds being broken up, *double decomposition* takes place. Metathesis involves both decomposition and combination.

#### *Experiments.*

Exp. 57. Dissolve a bit of copper sulphate as large as a pin's head in a drop of water. Put the solution

on a knife blade. Observe the coppery stain where the solution rests.

In this case copper sulphate,  $\text{Cu SO}_4$ , is brought into contact with iron, Fe. The iron replaces, takes the place of, the copper; ferrous sulphate,  $\text{Fe SO}_4$ , is formed and copper, Cu, is set free, and forms a coating on the knife blade. The whole as represented by the equation  $\text{Cu SO}_4 + \text{Fe} = \text{Fe SO}_4 + \text{Cu}$ .

Exp. 58. Fill a test tube with water, invert it under water in a basin and raise it until its mouth is just under the level of the water in the basin. Plunge under the mouth of the test tube a bit of sodium as large as a grain of wheat wrapped up in a fragment of paper. The sodium will rise in the test tube, accompanied by a torrent of bubbles, which will displace the water and fill the tube. If, when full of gas, its mouth be closed with the thumb, the test tube may be lifted from the water. Light a match, approach it to the mouth of the tube and remove the thumb. The gas in the tube will catch fire. It is hydrogen that has been set free from the water by the sodium according to the equation,  $\text{H}_2 \text{O} + \text{Na} = \text{NaOH} + \text{H}$ . The NaOH, sodium hydroxide, formed has dissolved in the water and will reveal its presence by changing the colour of a bit of reddened litmus paper back to blue.

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In this example one atom of hydrogen has been replaced by one atom of sodium. Other substances, of which we shall name only potassium, are able to replace hydrogen, atom by atom. Certain other substances combine with hydrogen atom with atom; we name only chlorine. Hydrogen, sodium, potassium



and chlorine are called monads, or are said to be univalent.

Into some dilute sulphuric acid drop a shred of zinc. Bubbles will speedily gather on the zinc, detach themselves, and rise through the liquid. If collected and examined they will be found to consist of hydrogen. In this case one atom of zinc has replaced two atoms of hydrogen,  $\text{H}_2 \text{SO}_4 + \text{Zn} = \text{Zn SO}_4 + \text{H}_2$ . Some substances, as calcium and magnesium, replace two atoms of hydrogen by one atom, and some substances, as oxygen and sulphur, combine one atom with two of hydrogen. Calcium, magnesium, oxygen and sulphur are called dyads, or are said to be bivalent.

Aluminum, nitrogen and phosphorus are triads, are trivalent; carbon and silicon are tetrads, are quadrivalent.

Groups of atoms, molecules, are often univalent, bivalent, trivalent, etc., and replace or are replaced by atoms or other molecules accordingly. Such groups of atoms are called radicals, and often retain their identity, replacing atoms or other radicals and being themselves replaced as wholes through long series of chemical changes.

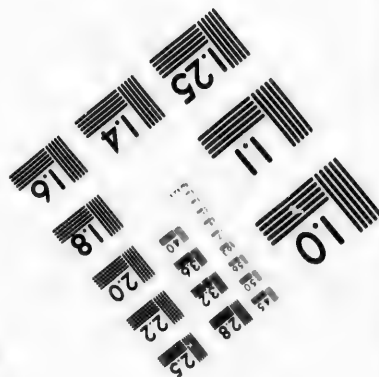
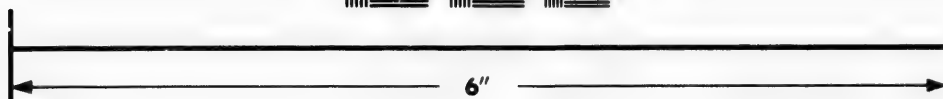
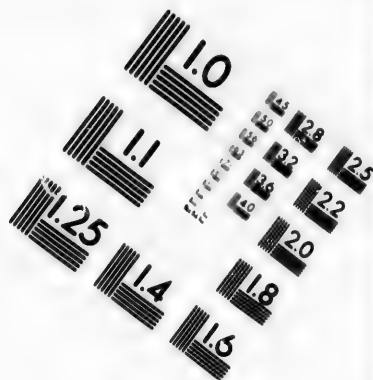
### *Experiment.*

Exp. 59. Dissolve a crystal of silver nitrate,  $\text{Ag NO}_3$ , as large as a pin's head in a half wine glass of water, and in another glass of water dissolve a pinch of common salt,  $\text{Na Cl}$ . Let a drop of the solution of salt fall into the solution of silver nitrate, and watch the white cloud that forms.

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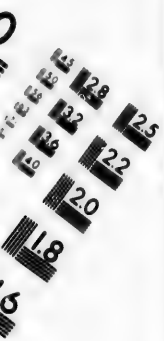
The white cloud is silver chloride; the reaction that has taken place is indicated by the equation





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$\text{Ag NO}_3 + \text{Na Cl} = \text{Na NO}_3 + \text{Ag Cl}$ . Both the silver nitrate and the sodium chloride have been decomposed and their constituents have interchanged with one another. Hence the action is called double decomposition.

Experiment 59 illustrates a very important law of metathesis which may be thus stated. If by any rearrangement of the substances present together in a solution an insoluble substance can be formed, it will be formed and precipitated.

Silver nitrate,  $\text{Ag NO}_3$ , is readily soluble in water ; so also is sodium chloride  $\text{Na Cl}$ . But if solutions of these salts be mixed, as much silver chloride,  $\text{Ag Cl}$ , a very insoluble salt, as can be formed, is at once formed, and is deposited as a heavy precipitate. If in the mixed solutions the  $\text{Na Cl}$  and  $\text{Ag NO}_3$  be present in equivalent amounts, that is molecule for molecule each atom of silver will find its equivalent atom of chlorine, will unite with it and will be precipitated, the whole of the silver and the whole of the chlorine disappearing from the solution and only sodium nitrate  $\text{Na NO}_3$  remaining dissolved. If there be an excess of the silver nitrate, all chlorine will be precipitated as  $\text{Ag Cl}$  and the water will hold both  $\text{Na NO}_3$  and  $\text{Ag NO}_3$  in solution. If, on the other hand, there be an excess of sodium chloride, all the silver will be deposited and the supernatant water will contain both  $\text{Na NO}_3$  and  $\text{Na Cl}$ , and only these.

A similar law holds good in case of fusion ; but in this case substances are removed from the influence of other substances present by volatilization. If in the fusion of any number of substances together, any rearrangement could give rise to a substance volatile at the temperature of the fusion, that substance will be formed, and will escape in the gaseous state.

Such considerations explain the apparent inversion of the order of affinities which is observed in certain instances. Thus *in water* potassium carbonate is decomposed by acetic acid; potassium acetate is formed and gaseous carbon dioxide escapes. Here the volatility of the carbon dioxide aids the reaction. But if through a solution of potassium acetate *in alcohol* a stream of carbon dioxide be passed potassium carbonate will be formed and precipitated, for it is insoluble in alcohol, and acetic acid will be set free. Here the insolubility of the potassium carbonate determines the action.

In like manner we may explain the influence of mass in determining decompositions. If steam be passed over iron filings heated red hot in a tube oxide of iron will be formed and hydrogen will be liberated and swept on by the atmosphere of steam. But if hydrogen be passed over the same oxidized filings, heated to the same temperature in the same tube, the filings will be deoxidized, vapour of water will be formed and will be swept onward by the atmosphere of hydrogen.

Tables of the strength of affinity of different substances for each other have been formed which are useful when the circumstances are accurately and fully stated, but which are apt to be misleading if applied in changed conditions.

## CHAPTER V.

### CHEMICAL PROPERTIES OF THE ELEMENTS MOST IMPORTANT IN AGRICULTURE, AND OF THEIR SIMPLE COMPOUNDS.

These elements are four gases—oxygen, nitrogen, hydrogen and chlorine; four non-metallic solids—carbon, sulphur, phosphorus and silicon; and seven metals—potassium, sodium, calcium, magnesium, iron, manganese and aluminum.

§ 1. Oxygen. Symbol, O; atomic weight, 16. As this gas constitutes nearly one-fourth of the air we breathe, it will be readily seen that it is destitute of smell, of taste and of colour. To its presence air owes its power of supporting combustion and respiration. When unmixed it may be distinguished from common air by two remarkable properties. If a vessel be filled with it, and a lighted taper introduced, the flame is greatly increased in size and brilliancy, and if an animal be introduced, its vital functions are stimulated and excited to such an extent that fever and death in a short time result. Oxygen is very abundant in nature, combining with a greater range of substances than any other element, fluorine perhaps excepted. It constitutes 23 per cent. of the weight of the atmosphere. It exists in still larger proportion in water, nine pounds of which contain eight of it. If iron be exposed to air and moisture, it rusts and increases in weight. This rust is a combination of iron with the oxygen of the air, or of water; and is identical with some of the ores from which iron is obtained. Many

of the ores of other metals, and the majority of rocks and earths comprising the surface of our globe, are similar compounds of metals and other substances with oxygen, so that this gas, in its pure state invisible, and only a little heavier than common air, is capable, when combined with metals and other substances, of assuming the liquid and solid states, and in these forms constitutes nearly one-half of the weight of the crust of our globe, and of the bodies of its animal and vegetable inhabitants.

The most striking property of oxygen, its power of supporting combustion, which has been already illustrated in Exp. 54, may be further shown as follows:—

*Experiment and Example.*

Exp. 60. Into an open test-tube four or five inches long put half a teaspoonful of powdered chlorate of potash mixed with half its bulk of clean sand. Heat the mixture over a spirit lamp. Gas will soon be given off in considerable quantity. Hold in the mouth of the test-tube an extinguished match, of which the tip is still glowing. It will be rekindled and burn vividly. By arranging the experiment, as in Fig. 5, the gas given off may be collected.

This property of rekindling into flame a bit of glowing wood is used as a test of oxygen gas; but it is by no means a sensitive test, as it is applicable only when uncombined oxygen predominates in a gaseous mixture.

98. Find the specific gravity of oxygen compared with hydrogen and with air.

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§ 2. *Nitrogen*. Symbol, N; atomic weight 14. As nitrogen constitutes 77 per cent of the weight of the

atmosphere, it will be rightly inferred that it is a gas without color, taste, or smell. It does not itself burn, neither will it support the combustion of other bodies; and animals and plants die when confined in it. Nitrogen enters into combination with difficulty and readily disengages itself from many of its combinations. Therefore compounds containing nitrogen are unstable, apt to decompose, sometimes with explosive violence. In air it is merely mixed with and serves to dilute oxygen and to prevent it from acting on both living beings and dead matter, with too great violence and rapidity.

*Experiment and Example.*

Exp. 61. Collect and examine nitrogen thus: Make a little stool with legs of wire three inches long and a top of thin wood one inch square. Set it to stand in a soup plate full of water. On the top put a bit of phosphorus as large as a pea; set fire to it, and invert over it a quart gem jar with the mouth dipping into the water. First air will escape from the jar, because it expands with the heat. White fumes of phosphoric anhydride,  $P_2O_5$ , will fill the jar. Water will rise in the jar showing that a part of the air is consumed. The phosphorus will be extinguished before it is all consumed, and before the air has disappeared. Let the whole stand for a while. Water will continue to rise in the jar as it cools, and care must be taken to supply water to the plate so as to keep the mouth of the jar always covered. The white fumes will gradually disappear dissolved in the water; slip a piece of paper under the mouth of the jar, while still under water; fold it up around the mouth of the jar, lift the jar out of the water while wrapped in the paper, and

keeping the paper over the mouth set the jar upright. Hang an end of lighted candle on a wire and dip it into the jar, removing the paper for that purpose. The candle will go out. The gas in the jar is nitrogen; it looks like air, but it will not support combustion.

There is no easy direct test for free nitrogen. It is recognized by its negative properties. A colourless gas which has no smell, which does not burn, nor support combustion, nor produce a precipitate in lime water, is probably nitrogen.

99. Calculate the specific gravity of nitrogen compared with hydrogen and with air.

### § 3. *Hydrogen*. Symbol H.; atomic weight 1.

#### *Experiments.*

Exp. 62. Throw a bit of sheet zinc, one inch square, and two or three iron tacks into a mixture of four or five parts of water to one of sulphuric acid. Observe the formation and rise of bubbles.

Exp. 63. Invert a test tube filled with water over the ascending stream of bubbles till it is filled with the gas; remove the test tube mouth downward and approach a lighted match to the mouth. If the arrangement like that of Fig. 5 without the lamp be used with zinc, iron and sulphuric acid in the corked test tube, the hydrogen may be collected in the inverted test tube. When full cover the mouth of the tube with your thumb, turn it mouth upward, hold a lighted match three inches above the mouth and remove your thumb.

Like oxygen, nitrogen, and their mixture, air, hydrogen is a colorless gas, without taste or smell; it is however more than 14 times lighter than air, and will



not support life or combustion, but on the other hand is itself very combustible; forming water  $H_2O$ , by union with oxygen,

The presence of hydrogen in any substance is recognized by the formation of water, when the substance is sufficiently heated in contact with oxygen.

Exp. 64. Bury a bit of tallow as large as a pea in half a teaspoonful of copper oxide in the bottom of a long test tube. Take care that the test tube, tallow and copper oxide are quite dry; holding the test tube nearly horizontal, heat the end of it strongly by a spirit lamp. Observe the moisture that will condense in the cool end of the tube, proving that tallow contains hydrogen.

As mercury is a liquid metal, so hydrogen is a gaseous metal, and by the united influence of great pressure and extreme cold it has of late been reduced to the metallic form.

As stated above, hydrogen is combined with oxygen to form water, of which the formula is  $H_2O$ . With nitrogen it forms ammonia, of which the formula is  $H_3N$ . Another very important compound is nitric acid, of which the formula is  $HNO_3$ . These compounds will be presently considered.

*Example.*

100. What information respecting the vapour of water and the gas ammonia is given by the statement that their formulæ are  $H_2O$  and  $H_3N$ ?

Water;  $H_2O$ . The physical properties of water have been already mentioned, page 24. Here it will

be necessary to advert to one or two of its chemical properties.

When hydrogen is burned, or when substances containing hydrogen are burned, or decay in air, water is formed by the union of the hydrogen with oxygen. Sometimes water is decomposed in nature's chemistry ; especially when animal or vegetable substances are decaying, or when some metals, as iron, are rusting under water. In such circumstances many complicated reactions take place, one result of which is that a part of the hydrogen of the water is sometimes, though rarely, set free. More frequently it unites with other substances that may be present, as with nitrogen to form ammonia,  $\text{NH}_3$ , with carbon to form marsh gas, methyl hydride,  $\text{CH}_4$ , with sulphur to form hydrogen sulphide,  $\text{H}_2\text{S}$ , or with phosphorus to form hydrogen phosphide,  $\text{H}_3\text{P}$ .

Water unites chemically with many substances, as with quick-lime to form slaked lime. Quick-lime, as stated before, is  $\text{Ca O}$  ; but if water be poured on it, heat is evolved, the lime absorbs water, and crumbles into a fine powder which has the chemical composition  $\text{Ca H}_2\text{O}_2$ . The chemical reaction is indicated by the equation  $\text{Ca O} + \text{H}_2\text{O} = \text{Ca H}_2\text{O}_2$ .

#### *Experiment and Example.*

Exp. 65. Pour on an ounce of quick-lime an ounce of water. Observe the effect. Dry the resulting powder thoroughly and see how nearly the weight corresponds to the theoretical weight.

101. Find the theoretical weight of slaked lime resulting from the preceding experiment.

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Again water unites with many substances in the act of crystallization. The cubes of common salt

referred to on page 32 are free from water; but crystals of blue vitriol, copper sulphate, contain more than one-fifth of their weight of water, and water constitutes two-thirds of the weight of soda crystals.

### *Experiments.*

Exp. 66. On a hot stove put a pinch of common salt, a crystal of alum, one of blue vitriol and one of washing soda; note their behavior.

*Ammonia*;  $H_3N$ . Exp. 67. Mix a small pinch of sal-ammoniac with an equal quantity of slaked lime, slightly damp, and heat the mixture gently in a test tube over a spirit lamp. Smell it. Hold a bit of damp, red litmus paper in the fumes.

The smell is due to ammonia,  $H_3N$ , a compound of nitrogen and hydrogen. Though composed of two gases destitute of taste and smell, and itself a gaseous substance, it has a burning taste and a pungent smell. Water absorbs more than 1,000 times its bulk of ammonia at a temperature of  $32^\circ$ , the amount diminishing with increase of temperature. Water holding ammonia in solution constitutes the common spirit of hartshorn, whose taste and smell are those of the ammonia which it contains. Ammonia dissolved in water has alkaline properties, combining with acids to form salts.

Ammonia is easily recognized by its smell conjoined with its power of changing to blue the color of a bit of damp, red litmus paper. Ammonia in combination is set free by calcium hydrate and is then recognized as in Exp. 67. (See page 99).

*Nitric Acid* is a liquid compound of hydrogen, nitrogen and oxygen,  $HNO_3$ . When somewhat

diluted with water it is the substance known as aquafortis. It is a strong acid. It may be recognized even in combination by the magnificent red colour produced when nitric acid or any nitrate is brought into contact with a solution of brucine in concentrated sulphuric acid.

*Examples.*

102. How much O, and how much H, in 9 lbs. water? in one imperial gallon? in one cubic foot? in one ton?

103. What are the proportions by volume and by weight of hydrogen, nitrogen and oxygen in nitric acid.

104. What weight of O, of N and of H is contained in 504 lbs. nitric acid?

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§ 4. Chlorine. Symbol, Cl; atomic weight 35.5.

*Experiments.*

Exp. 68. Put a tablespoonful of chloride of lime into a tall narrow jar, pour on it an equal bulk of hydrochloric acid, and loosely cover the jar with a card. Effervescence will ensue and the jar will be filled with a transparent yellowish gas, chlorine, which is so heavy that it will remain in the jar, if large enough to hold it all. The odour is peculiar and powerful, but it must be smelt at a distance, as the gas is dangerously irritating to the lungs.

Exp. 69. Sprinkle filings of antimony into the jar. They will take fire and burn as they fall.

Exp. 70. Dip the end of a strip of blotting paper into spirits of turpentine and then insert it into the jar of chlorine. The turpentine will take fire and

burn with a dull red flame, emitting dense clouds of unconsumed carbon.

---

Chlorine is a greenish yellow gas, heavier than air, of a powerful odour and quite irrespirable. In it many metals and hydrogen may be burned, but carbon cannot. Exp. 33 furnishes a test for chlorine.

*Hydrochloric Acid*, HCl. The result of the combustion of hydrogen in chlorine is hydrochloric acid gas, which is highly soluble in water. At a temperature of  $60^{\circ}$ , one volume of water dissolves 450 volumes of this gas. The solution is sold under the names of hydrochloric acid, muriatic acid and spirit of salt.

*Examples.*

105. Find the specific gravity of chlorine compared with hydrogen and with air.

106. The formula of spirits of turpentine is  $C_{10}H_{16}$ ; how many molecules of hydrochloric acid are formed by the combustion in chlorine of one molecule of turpentine?

107. What weight of chlorine is needed for the combustion of one ounce of turpentine, and what weight of carbon will be set free?

108. What is the composition by volume and by weight of hydrochloric acid gas? and what is its specific gravity compared with air?

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§ 5. *Carbon*. Symbol, C; atomic weight, 12. This substance is most familiarly known as common wood charcoal, which consists of carbon with a small mixture of potash and earthy and other matters; it also exists in large quantity in mineral coal; black-lead is

almost pure carbon; and the diamond exhibits it in its purest form. The diamond differs from wood charcoal only in being pure and crystalline. Carbon is infusible and insoluble, and enters into more complex forms of combination than any other substance. It is an essential component of every animal and vegetable product. Because of its surface attraction dry porous charcoal, as that of wood or bones, possesses the remarkable property of absorbing from the air large quantities of gases and other exhalations; hence its use in depriving putrid meat and other decaying substances of their offensive smell; it also absorbs from water many organic substances which it may contain, and even some of the inorganic saline substances.

When charcoal is burned it combines with oxygen, forming carbon dioxide,  $\text{CO}_2$ , a gas which disappears in the atmosphere; and when animals breathe, the oxygen of the air which enters their lungs, combines with carbon derived from the blood, and is returned to the atmosphere in this same form of carbon dioxide.

The fact that carbon, when exposed at a high temperature to an abundant supply of oxygen, unites with it to form carbon dioxide, enables the chemist to detect the presence of carbon in any other form than that of carbon dioxide itself. (See Exp. 77 below.)

### *Experiments.*

Carbon Dioxide;  $\text{CO}_2$ . Exp. 71. Pour dilute hydrochloric acid on bits of limestone in a tall, loosely covered glass. A brisk effervescence will ensue, and the air in the glass will be displaced by a heavy invisible gas, the presence of which may be demonstrated by lowering into it a lighted end

of candle, which will be immediately extinguished, while the gas itself does not take fire.

Exp. 72. Pour this gas from the jar into a tumbler, and show that the tumbler has been filled, by lowering a lighted match into it.

Exp. 73. Pour the gas from the jar on a lighted candle, so as to extinguish it.

---

Carbon dioxide is a heavy, colorless gas which extinguishes flame, is not itself combustible, and which speedily suffocates animals that inhale it. When dissolved in water it forms carbonic acid,  $\text{CO}_2 + \text{H}_2\text{O} = \text{H}_2\text{CO}_3$ , a weak acid which reddens vegetable blue colors, has a sour taste, and is capable of combining with *alkalies* such as potash and soda, with alkaline earths such as lime and with other bases.

Two of the modes in which carbon dioxide is produced in nature, namely, combustion and animal respiration, have been already mentioned; but it may be formed in many other ways. It exists in large quantity in limestone and other rocks, and is given out by volcanoes, and brought to the surface by springs; it is also sometimes disengaged from fissures, etc., in mines, and accumulates in deep cellars, wells, etc., forming the "choke damp" which occasionally proves fatal to persons incautiously entering such places. When wood, straw, or similar substances, are exposed to air and moisture, a kind of slow combustion, which we call decay, commences, part of their carbon and hydrogen combine with the oxygen of the air, and form carbon dioxide and water, until at length nothing remains but a coaly mass capable of little further change.



In consequence of these processes, it is evident that carbon dioxide must be constantly produced and added to the atmosphere; and, if this proceeded unchecked, it would at length accumulate in so great quantity, that animal life would be destroyed. But it is found that the quantity of carbon dioxide in the air does not equal the one-thousandth part of its weight, and is not increasing. It is also known that water is capable of dissolving more than its own bulk of carbon dioxide, and consequently that rain and surface water are always impregnated with it; and it is found by experiment, that plants supplied with the air and water containing this gas, apply its carbon to the formation of wood and other vegetable products. It thus appears that the carbon dioxide produced by burning, breathing, decay, and other processes, and which would otherwise contaminate the atmosphere, is employed as the food of plants, and is thus, by the wise arrangement of a beneficent Providence, made a source of supplying the most valuable substances which the earth affords to man.

*Experiments and Examples.*

Exp. 74. Dissolve a little baking soda in water and let a few drops fall into a clear solution of lime water. Observe the white cloud that is formed. Drop in two or three drops of hydrochloric acid, and watch the disappearance of the cloud. The cloud is composed of calcium carbonate, which is dissolved by the hydrochloric acid.

Exp. 75. Dissolve a little potassium nitrate in water, and drop a little into lime water; if the potassium nitrate be pure no cloud will be formed. The absence of carbonic acid is demonstrated.



Exp. 76. Fuse a little of the potassium nitrate in a short wide tube of hard glass, held over a spirit lamp by a handle of twisted wire, and throw into it a bit of charcoal as large as a grain of wheat. Brilliant deflagration will take place. Let the tube and its contents cool. Dissolve a little in water and drop the solution into lime water. A white cloudiness will show that carbonic acid is now present formed by the union of the carbon with oxygen derived from the fused potassium nitrate.

Exp. 77. Repeat this experiment with a bit of wood, of starch, of sugar, of finger nail, of beef, or of any part of any vegetable or animal, and demonstrate the truth of the universal presence of carbon in animal and vegetable structures.

109. How much carbon dioxide is formed by the combustion of 10 lbs. carbon ?

110. What is the specific gravity of carbon dioxide compared with hydrogen and with air ?

111. The amount of carbon dioxide in the air is about four ten-thousandths of its volume, what proportion is that of its weight ?

112. If the weight of the air on every square inch of surface be 14.7 lbs., and if six ten-thousandths of its weight be carbon dioxide, how many tons of carbon dioxide hang over an acre ?

113. The conditions being as in the preceding question, how many tons of carbon are afloat over an acre of land ?

§ 6. Sulphur. Symbol S; atomic weight 32. This is a well-known, brittle, yellow solid. When heated it undergoes a series of of interesting changes.

*Experiments.*

Exp. 78. Put a teaspoonful of sulphur into a test tube, heat it over a spirit lamp and watch it. First it melts into an amber colored, thin liquid. Its temperature is now  $235^{\circ}$ , and if cooled at this stage it appears again as ordinary yellow sulphur. If still further heated it grows darker and thicker, so that at  $445^{\circ}$  it can scarcely be poured out of the tube. Heated still more highly it again becomes thin, but is of a dark brown color. If at this stage poured into cold water, it becomes a soft, tough, elastic, dark brown mass.

Exp. 79. Put a part of this brown mass into boiling water and observe what takes place.

Exp. 80. Put the rest of the dark brown mass aside for a month or two and then examine it again.

Exp. 81. Heat some more sulphur in a test tube until it boils, the temperature is then  $825^{\circ}$ . Observe the color of the vapour. Pcur out some of the vapour on a cold slate. Flowers of sulphur, as the fine yellow dust is called, will be formed.

Exp. 82. Set fire to a little heap of sulphur. Observe the colour of the flame and the suffocating odour. Hold a damp bit of blue litmus paper in the fumes, and see it first turn red, then white.

---

The fumes produced in the last experiment are a gas, sulphur dioxide,  $\text{S O}_2$ , which when dissolved in water forms sulphurous acid;  $\text{SO}_2 + \text{H}_2 \text{O} = \text{H}_2 \text{SO}_3$  indicates the reaction. Sulphurous acid destroys most vegetable colors. The solution of this acid in water slowly absorbs more oxygen from the air; thus  $\text{H}_2 \text{SO}_3 + \text{O}$  becomes  $\text{H}_2 \text{SO}_4$ , sulphuric acid. This in a concentrated form is a dense, oily, intensely sour and most strongly corrosive liquid, exhibiting all acid

properties in their highest degree. In commerce it is called oil of vitriol

*Examples.*

114. With what weight of oxygen will 80 lbs. of sulphur combine in burning?

115. A certain sample of commercial sulphuric acid contains two per cent of water, the rest being pure acid, how much sulphur, hydrogen and oxygen are in each 50 lbs.

116. What is the specific gravity of sulphur dioxide compared with hydrogen and with air?

Substances containing sulphur when heated by the blowpipe on charcoal give the odour of burning sulphur. Soluble sulphates give, with barium chloride, a white precipitate, which is quite insoluble in the strongest acids.

§ 7. *Phosphorus*. Symbol, P; atomic weight 31. Phosphorus is a solid substance, in appearance somewhat resembling bees-wax. It is highly inflammable, taking fire at ordinary temperatures, so that it must be kept under water and handled with extreme caution. It burns with an intense light, evolving dense clouds of white smoke,  $P_2O_5$ , phosphoric anhydride. Phosphoric anhydride dissolves readily in water, forming a strongly acid solution, according to the following reaction,  $P_2O_5 + 3(H_2O) = 2(H_3PO_4)$ ; one molecule of phosphoric anhydride, together with three molecules of water, forms two molecules of phosphoric acid.

Free phosphorus is never met with in nature. The phosphates, when they are fused with a bit of magnesium in a closed tube and after cooling are moistened, give a characteristic odour like decaying fish.

*Examples.*

117. What weight of oxygen is required for the complete combustion of 1 lb. 15 oz. of phosphorus? What weight of phosphoric anhydride will be formed?

118. Find the weight of water necessary to change 4 lbs. 7 oz. of phosphoric anhydride into phosphoric acid? How much phosphoric acid will be produced?

§ 8. *Sodium.* Symbol Na; atomic weight, 23. Sodium is a silver-white metal, so soft as to be readily cut with a knife or flattened between the fingers so light as to float on water, and so readily acted on by oxygen as to tarnish immediately when exposed to air, and to decompose water with great rapidity, replacing or half of its hydrogen. These reactions are indicated by the following equations:  $2 \text{Na} + \text{O} = \text{Na}_2 \text{O}$ , sodium monoxide; and  $\text{Na} + \text{H}_2 \text{O} = \text{H} + \text{NaOH}$ , the last substance is called sodium hydroxide or caustic soda. Sodium monoxide absorbs water with great avidity and with the evolution of much heat, forming with the water sodium hydroxide, according to the equation  $\text{Na}_2 \text{O} + \text{H}_2 \text{O} = 2 (\text{NaOH})$ . Sodium hydroxide is an alkali and, as such, is very soluble in water, and unites with acids to form highly soluble salts.

Sodium takes fire in chlorine, forming sodium chloride, common salt, an important adjunct to the food of men and of animals.  $\text{Na} + \text{Cl} = \text{NaCl}$ . Sodium chloride is also formed by the interaction of either sodium monoxide or sodium hydroxide with hydrochloric acid; thus,  $\text{Na}_2 \text{O} + 2 \text{HCl} = 2 \text{NaCl} + \text{H}_2 \text{O}$ , or  $\text{NaOH} + \text{HCl} = \text{NaCl} + \text{H}_2 \text{O}$ . Similarly nitric acid acting on either the monoxide or the hydroxide forms sodium nitrate: thus,  $\text{Na}_2 \text{O} + 2 \text{HNO}_3 = 2 \text{NaNO}_3 + \text{H}_2 \text{O}$ , or  $\text{NaOH} + \text{HNO}_3 = \text{NaNO}_3 + \text{H}_2 \text{O}$ , sodium nitrate and water.

With carbonic acid sodium forms two salts, the sodium carbonate and the hydrogen sodium carbonate commonly called sodium bicarbonate. The reactions are indicated by the following equations:  $\text{Na}_2\text{O} + \text{H}_2\text{CO}_3 = \text{Na}_2\text{CO}_3 + \text{H}_2\text{O}$ ; and  $\text{NaOH} + \text{H}_2\text{CO}_3 = \text{NaHCO}_3 + \text{H}_2\text{O}$ . Similarly with sulphuric acid are formed sodium sulphate and hydrogen sodium sulphate or sodium bisulphate, as by the following equations:  $\text{Na}_2\text{O} + \text{H}_2\text{SO}_4 = \text{Na}_2\text{SO}_4 + \text{H}_2\text{O}$ , and  $\text{NaOH} + \text{H}_2\text{SO}_4 = \text{NaHSO}_4 + \text{H}_2\text{O}$ .

With phosphoric acid,  $\text{H}_3\text{PO}_4$ , sodium forms three salts according as one, two or three atoms of the hydrogen are replaced by sodium, the monosodium phosphate,  $\text{NaH}_2\text{PO}_4$ , the bi-sodium phosphate,  $\text{Na}_2\text{HPO}_4$ , and the ter-sodium phosphate  $\text{Na}_3\text{PO}_4$ .

Sea-salt,  $\text{NaCl}$ , whether directly derived from the sea, or from the residue of dried-up ancient seas, rock-salt, dug out from beneath the accumulated sands, clays and limestones that in the course of geological ages have been heaped over it, is the source from which most of the salts of soda used in the arts are derived.

Another sodium salt, sodium nitrate,  $\text{NaNO}_3$ , constitutes extensive beds in the rainless districts of Peru and Chili. This substance, often called in commerce Chili saltpetre, is extensively used as a manure.

### *Examples*

119. How much sodium and how much oxygen are contained in 1 lb. 15 oz. of sodium monoxide? and how much hydrogen is there in 350 grains of sodium hydroxide?

120. In 117 lbs. common salt how many pounds of sodium and how many of chlorine are there? and if the chlorine were liberated at the temperature of  $60^\circ$ ,

and the pressure 30 inches of mercury, how high must a room 7 feet square be in order to hold it all?

121. Find what weight of each of the following substances contains one ounce of sodium: *a.* sodium carbonate, *b.* hydrogen sodium carbonate, *c.* sodium sulphate, *d.* hydrogen sodium sulphate, *e.* sodium nitrate, *f.* monosodium phosphate, *g.* bi-sodium phosphate, *h.* ter-sodium phosphate, *i.* sodium chloride.

§ 9. *Potassium.* Symbol K; atomic weight 39. The description of sodium and its compounds given above is precisely applicable to potassium, except that potassium imparts a violet colour to colourless flames, that potassium chloride is not common salt, is not used as a condiment, and is not the chief source of potassium salts, nor is potassium nitrate found like sodium nitrate in extensive beds in America, but in South Africa. With these exceptions read all that is said under the head of sodium again, substituting the words potassium and potash for sodium and soda, and in all the formulæ and equations of reaction inserting the symbol K instead of Na. Any substance which imparts to a colourless flame a hue that appears purple when seen through thick cobalt-blue glass, contains potassium.

*Example.*

122. Write out the equations which show the mode of formation of *a.* potassium monoxide, *b.* caustic potash, *c.* potassium chloride, *d.* potassium nitrate, *e.* the two potassium carbonates, *f.* the two potassium sulphates, and *g.* the three potassium phosphates. Give the names of the carbonates, the sulphates, and the phosphates.

Wood ashes contain much potash which is extracted as lye by lixiviation. The lye is boiled down until all the water is evaporated ; the solid residue is fused at a red heat and forms the potash of commerce. Further purification produces pearlash, which, however, requires further treatment in order to derive from it pure potassium carbonate,  $K_2CO_3$ . Most of the salts of potash are thus derived from the ashes of trees and other land plants.

For about 35 years past a new source of supply of potash has been opened up in Stassfurt, in Saxony, where thick beds of minerals containing much potash have been discovered overlying a deposit of rock salt. From this locality very large quantities of minerals containing a high percentage of potash are exported in a crude or in a partially purified state, to be used as manure under the names of kainit, abraum salt, muriate of potash and sulphate of potash. Very recently beds of nitrate of potash have been discovered in South Africa.

### *Examples.*

123. If three ounces of potassium be burned in air, how much potassium oxide will be formed ?

With how much water will 47 grains of  $K_2O$  unite, and what will be the weight of the resulting potassium hydroxide ?

124. In 101 lbs. of potassium nitrate how much nitrogen, and how much potassium are there ?

125. If potassium in a manure be worth 6c a pound, and nitrogen 15c a pound, what is the value as manure of one ton, 2,000 lbs., of potassium nitrate ?

126. If its value as a manure be estimated by the potassium it contains at 6c a pound, what is the value



of 100 lbs. of potassium monoxide? of potassium hydroxide? of potassium chloride? of potassium carbonate? of potassium sulphate?

127. A certain sample of potashes gave 44% of potassium carbonate and 40 % of potassium hydroxide. What was its value per ton as manure, this being determined solely by the potassium present, at 6c a pound?

128. What is the weight of each constituent in 1,000 grains of each of the following substances: *a.* potassium monoxide, *b.* potassium hydroxide, *c.* potassium chloride, *d.* potassium nitrate, *e.* potassium sulphate, *f.* hydrogen potassium sulphate, *g.* potassium carbonate, *h.* hydrogen potassium carbonate, *i.* mono-potassium phosphate, *j.* bi-potassium phosphate, *k.* ter-potassium phosphate.

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Note.—Compounds of ammonia are most readily understood by assuming that when one molecule of ammonia meets one molecule of water, the atoms rearrange themselves as by the following equation:  $\text{NH}_3 + \text{H}_2\text{O} = (\text{NH}_4) \text{HO}$ . The molecule  $\text{NH}_4$ , to which chemists give the name ammonium, has never been isolated, but it seems to play in many reactions the same part as one atom of sodium or one of potassium would do. Thus  $(\text{NH}_4)\text{HO}$ , like  $\text{NaHO}$  or  $\text{KHO}$ , is a caustic alkali; and as these are respectively named sodium hydroxide and potassium hydroxide, so that may be named ammonium hydroxide. Again as there are sodium and potassium chlorides, nitrates, carbonates, sulphates and phosphates, there are ammonium chloride, commonly called sal ammoniac,  $(\text{NH}_4)\text{Cl}$ ; ammonium nitrate,  $(\text{NH}_4)\text{NO}_3$ ; ammon-



ium carbonate,  $2(\text{NH}_4)\text{CO}_3$ ; ammonium hydrogen carbonate,  $(\text{NH}_4)\text{HCO}_3$ ; ammonium sulphate,  $2(\text{NH}_4)\text{SO}_3$ ; and three phosphates, the mono-ammonium phosphate,  $(\text{NH}_4)\text{H}_2\text{PO}_4$ ; the bi-ammonium phosphate,  $2(\text{NH}_4)\text{HPO}_4$ ; and the ter-ammonium phosphate,  $3(\text{NH}_4)\text{PO}_4$ . A comparison of the formulæ of these salts with those of the corresponding sodium and potassium salts will show the correspondence of the molecule  $\text{NH}_4$  to the atoms Na and K.

§ 10. *Calcium.* Symbol Ca; atomic weight 40

This is a light, yellow metal which oxidizes readily in air, and when heated burns with a bright red light, producing abundant white clouds of quick-lime, calcium oxide,  $\text{CaO}$ . Calcium oxide readily combines with water, evolving great heat in the act of combination;  $\text{CaO} + \text{H}_2\text{O} = \text{CaO}_2\text{H}_2$ , calcium hydroxide, slaked lime. Calcium hydroxide is an alkaline earth soluble in water to some extent, but much less so than the alkalies, and entering into combination with acids to form an interesting series of salts.

The alkaline earths are distinguished from the alkalies by the comparative insolubility of their carbonates as already exemplified in Exp. 56, and again in Exp. 83 below.

*Experiments.*

Exp. 83. Into a weak solution of sodium carbonate drop a drop of lime water. The white cloud produced is calcium carbonate as indicated by the equation  $\text{Na}_2\text{CO}_3 + \text{CaO}_2\text{H}_2 = \text{CaCO}_3 + 2\text{NaOH}$ .

Exp. 84. Blow air from the lungs into the water holding the calcium carbonate in solution. After a while the white cloud of calcium carbonate will

disappear, for it is soluble in water holding carbonic acid in solution.

Calcium carbonate is found abundantly in nature in different states of aggregation as marl, chalk, limestone. When raised to a red heat these calcium carbonates lose their carbon dioxide and quick-lime remains;  $\text{Ca C O}_3 = \text{Ca O} + \text{C O}_2$ . As pointed out above, quick-lime absorbs water, and becomes slaked lime, which is mixed with more water and with sand to make mortar. Mortar hardens chiefly because the lime absorbs carbon dioxide from the air, and returns to the state of calcium carbonate.

Quick lime and slaked lime hasten the decomposition of many organic substances and set free the bases of many salts by combining with their acids.

Sulphuric acid and calcium oxide unite to form calcium sulphate;  $\text{H}_2 \text{ S O}_4 + \text{Ca O} = \text{Ca S O}_4 + \text{H}_2 \text{ O}$ . One molecule of calcium sulphate united to two molecules of water constitutes gypsum,  $\text{Ca S O}_4 + 2\text{H}_2 \text{ O}$ . When moderately heated, gypsum loses the two molecules of water and falls into a dry powder, plaster of Paris, but when again moistened it reabsorbs the water it had lost and becomes solid once more. For this reason it is much used in making plaster casts and ornaments.

There are three compounds of calcium and phosphoric acid whose relations to each other are of great interest to the farmer. They are:

Name.	Common Name.	Formula.
Tercalcium Phosphate	Bone-ashes	$\text{Ca}_3 \text{ P}_2 \text{ O}_8$
Bicalcium        "	Reverted Phosphate	$\text{Ca}_2 \text{ H}_2 \text{ P}_2 \text{ O}_8$
Monocalcium     "	Superphosphate	$\text{Ca H}_4 \text{ P}_2 \text{ O}_8$

Tercalcium phosphate constitutes the greater part of the ashes of burnt bones and constitutes large beds of a stony mineral named apatite. It is almost insoluble in pure water, but is very slowly soluble in water holding carbon dioxide in solution. Bicalcium phosphate is known in trade as reverted phosphate. It is more soluble than the ter-calcium phosphate, but very much less soluble than superphosphate.

*Examples.*

129. In 100 lbs. of quick lime, calcium oxide, how much calcium and how much oxygen are there?

130. What weight of phosphoric anhydride is there in 117 lbs. of monocalcium phosphate?

131. 74 lbs. slaked lime, calcium hydroxide, are exposed to a current of dry air containing carbon dioxide until all change ceases; what amount of  $\text{CO}_2$  will be absorbed, of  $\text{H}_2\text{O}$  evaporated, and of  $\text{Ca CO}_3$  produced?

132. Twenty pounds anhydrous gypsum,  $\text{Ca SO}_4$ , are mixed with seven pounds of water, making a damp cast; how many pounds of water will be evaporated in drying the cast?

§ 11. Magnesium. Symbol Mg; atomic weight 24. This is a silvery looking metal which slowly tarnishes in the air. When strongly heated it takes fire, burning with an exceedingly bright white light, giving off dense clouds of magnesia,  $\text{Mg O}$ . Magnesia is an alkaline earth, scarcely soluble in water, uniting with acids to form salts.

*Example.*

133. In 100 pounds of magnesia, how much magnesium, and how much oxygen?

§ 12. *Silicon*. Symbol Si ; atomic weight 28. This is known to the chemist as a brown powder, prepared with difficulty, and of no use when prepared ; but its oxide, silicon dioxide,  $\text{Si O}_2$  is most abundant in nature ; quartz, rock crystal, flint, sand are forms in which it occurs. It unites with alkalis, with alkaline earths, and with bases generally. A great part of the rocks of the earth, especially of the primary rocks, are mixtures of silica and the silicates. For example, granite is plainly seen to be a mixture of three minerals, one glassy and transparent, quartz ; one somewhat porcelain-like in appearance, felspar, and one in the form of scales intermixed with the others, mica. Quartz is silica ; felspar is potassium aluminum silicate ; and mica is in the main a complex silicate of aluminum, potassium and iron.

The silicates of the alkalis and alkaline earths are fusible and melt into transparent glass. Glass is tinted of various colours, some of them of great beauty, by various metals and their compounds.

*Example.*

134. In one ton of sharp sand, pure silica, how many pounds of oxygen, and how many of silicon are there ?

§ 13. *Aluminum*. Symbol Al ; atomic weight 27. This is a light metal not much heavier than glass, white and brilliant, intermediate in appearance between silver and polished steel, now used for various purposes in the arts. It unites with oxygen, forming a white powder, alumina,  $\text{Al}_2 \text{O}_3$ . This acts as a weak base ; it unites with silica, forming aluminum silicate, the principal ingredient of many minerals. Clay is a mixture of many substances in varying proportions,

but in which aluminum silicate and silica predominate. When a lump of clay is exposed to great heat, among other changes some of its particles undergo fusion, and bind the rest into a firmly coherent mass. According to the character and amount of other substances mixed in the clay, bricks, earthenware and porcelain are produced.

*Example.*

135. In 1,000 grains of alumina, how much aluminum is there?

§ 14. *Iron.* Symbol Fe; atomic weight 56.

§ 15. *Manganese.* Symbol Mn; atomic weight 55.

These are heavy metals occurring in the ashes of plants. The common metal iron everyone knows. On exposure to air and moisture it rusts, that is it combines with oxygen, and constitutes an oxide known as ferric oxide,  $\text{Fe}_2\text{O}_3$ , of which the yellow or brown rust of iron and red ochre are examples. This substance occurs in most soils, and gives to them a reddish or brownish color. There is another oxide of iron, ferrous oxide,  $\text{FeO}$ , having less oxygen, which occurs in some wet soils and bog waters. It has a greenish or greyish color, and when exposed to air passes into the ferric oxide. Common green vitriol is ferrous sulphate,  $\text{FeSO}_4$ . The oxides of iron occur in very small quantity in the ashes of plants.

Oxide of manganese occurs in still smaller quantity in plants, and is sometimes absent. It is hence not supposed to be essential to their healthy growth.

## CHAPTER VI.

### PLANTS, THEIR FUNCTIONS AND STRUCTURES.

§ 1. *Living Things.* Living things are distinguished from things destitute of life by two fundamental peculiarities. Living things have *definite active functions* to perform; and they cease to be when these are performed—they *die*. From the fact that they have active functions to perform arise two peculiarities; they are *organized*, that is, they have parts specially fitted to discharge their functions, and, since force is necessary for the performance of function, and since nothing creates force, every living thing requires that *force* shall be *supplied* to it from without. Organization implies parts subordinate to, but together constituting, a whole, an *individual*. Again, because individuals perish, preparation for the perpetuation of the race is made by processes of *reproduction*. New individuals begin life small in size, and incapable at first of performing all their functions, that is, they are immature. Hence living things both *grow* and *develop*. They grow by changing substances, more or less unlike themselves, into their own proper substance, and in doing this they add the new material between and among the minutest particles of their substance; that is they grow by *interstitial assimilation*. A necessary geometrical result of interstitial growth is a tendency to *rounded forms* in the outlines of living things. Living things, beginning immature, acquire with lapse of time increasing complexity of structure and of function, until maturity is attained.

After a greater or less period of full vigour, decay of the organism and diminution of power progress, until death closes the life-cycle of the individual. Reproduction tends to the renewal of the parental forms. Hence living things that are related to each other by a common ancestry are in all important respects alike. The sum total of living things that resemble one another, as much as the descendants of a known common ancestry resemble each other, constitutes a *species*.

X The following conspectus exhibits the most important peculiarities of living things and the relation of their peculiarities to each other:—

#### LIVING THINGS.

- |                     |   |  |
|---------------------|---|--|
| 1 Discharge         | ∴ | { are organized as individuals;  |
| functions           | ∴ | { require supplies of force from without.  |
|                     |   |  |
| 2 Die ∴ reproduce ∴ | { | grow { at the cost of food ;<br>by interstitial assimilation ;<br>and ∴ have rounded forms ; |
|                     | { | develop { from infancy to maturity,<br>old age and death ;                                   |
|                     | { | constitute species.  |

Living things, on the ground of difference of function, are divided into two kingdoms, vegetable and animal.

§ 2. *The Vegetable.* A vegetable is an organism designed to store up force, an animal to utilize force while dissipating it. The force which the vegetable stores up is sunlight; the work that is done by sunlight in the vegetable organism is the deoxidation of various compounds, chiefly carbon dioxide and water, the liberation of a part of the oxygen and the synthesis of the residues into the various combustible substances of which the plant is built up. Just as coal is a store of force utilized in the steam engine, so is the plant a store of force utilized in the animal that feeds upon it.



The power of the plant to employ sunlight in the deoxidation of the compounds on which it feeds, is absolutely dependent on the presence of chlorophyll, the green coloring matter of leaves; hence only the green parts of plants prepare their nutriment, and these act only in daylight.

Every plant uses up some of its own material in the work of organization. The seed in germinating, the bud in unfolding, the flower in developing, the fruit in ripening, absorb oxygen, exhale carbon dioxide, in fact undo a little of the work which the green parts of the plant have been doing at the expense of sunlight. This work of organization proceeds independently of sunlight, while the work of preparing material by deoxidizing carbon dioxide, etc., always demands sunlight.

Some plants have no chlorophyll, and so prepare none of their own material. All these are dependent on material previously prepared by other plants. Some of them are parasitic on other plants as the dodder which infests flax fields. Some develop in the interior of living plants, as the rust and the smut which invade the wheat plant, or as the fungus which destroys the potato.

Some of them develop in the bodies of animals, and are the cause of many painful and fatal diseases. Many of them, from the microscopic moulds that develop in decaying bread or cheese or jam, to the mushrooms that flourish in rich pastures or the gigantic woody excrescences that grow upon the boles of decaying trees, are saprophites; they arrest the progress of dead organized matter on its way to decomposition, consuming a part in order to organize the remainder into new forms of life.



The substances which constitute the food of plants when taken into the system of a vegetable, have entered into a chemical and vital laboratory, where they are destined to undergo a series of changes, ending in their assuming forms and properties very different from those which originally belonged to them. It is therefore necessary that we should consider the *organs* of plants ; the vessels or utensils as it were, which nature employs in converting the unorganized matter of the soil and air into food for men and animals.

The *general structure* of all plants is nearly the same. The wood of the hardest tree, as well as the stem of the most delicate herb, is composed of an immense number of very small tubes and cells, whose sides consist of woody matter, enclosing cavities suited for containing or transmitting sap or other fluids. These cells and tubes assume many different forms, varying from those of nearly round bags or bladders, to those of long pipes, sometimes extending through the whole length of a plant. They also differ very much in dimensions, direction and mode of arrangement ; and it is to these differences that we must ascribe the various degrees of coarseness and fineness, toughness and brittleness, hardness and softness, which we observe in the wood of different trees, as well as the various kinds of texture which appear in the organs of every individual plant. To examine these varieties of structure, and the purposes which they serve, is a pursuit full of interest and instruction ; for the present, however, we must content ourselves with a very general outline of the subject, taking for our example the structure of trees, which are the largest and most perfect specimens of vegetation.

The trunk and branches of a tree may be viewed as consisting of three parts—Bark, Wood and Pith. The true *Bark* consists of a tissue of cells, closely embracing the tree, of a white or brownish colour on the older parts of the trunk, and green on the young extremities of the twigs. This inner or true bark is covered and protected from the air by an outer skin or covering, which in some trees, as the white birch, consists of numerous thin and tough layers. In some plants, as the grasses, this outer bark is the only external covering which appears, and in these plants it often consists in part of dense inorganic matter, constituting the strongest part of the stem. The *Wood* is principally composed of cells and vessels of various forms and sizes, arranged lengthwise in the stem, and crossed by bundles of cells placed horizontally, and extending from the centre of the wood to the bark, so as to form thin plates stretching across the wood, and called the *silver grain*, or *medullary rays*. The office of these is supposed to be that of conveying fluids from the bark to the heart of the tree. The *Pith*, which is present only in young branches and small stems, consists of large cells placed horizontally, and it probably serves to store up superabundant sap till it is required by the plant. These structures, though most obvious in the trunk, are continued into the branches, and, in some degree, into the leaves. Though the structure which we have noticed prevails in trees, and in a great number of herbaceous plants, there is a large proportion of the vegetable kingdom which shows no regular arrangement of bark, wood and pith; and the whole of the grains and grasses are of this last kind. In these plants, however, the parts discharging the different functions of wood and bark are no

wanting, but rather intimately united instead of being separated into different portions. We may now consider the functions of those organs which belong to nearly all plants.

### § 3. *The Root.*

The larger branches of the root, like those of the trunk, consist of bark and wood; but in their smaller ramifications both bark and wood become soft, porous, and easily penetrated by water; and these minute and greatly divided extremities of the roots, penetrating to every part of the soil around a plant, are its true mouths or feeders. The spongy rootlets are capable of taking only fluid food; no particle of clay or other undissolved matter can enter them; they absorb water, and this in so large a quantity that a sunflower three feet high has been stated to draw from the soil thirty ounces of water in twelve hours of a sunny day. But the water of the soil is not pure; it contains a great variety of mineral and other substances in solution, and these it must carry to the roots of every plant which grows upon it.

That growing plants absorb water by the roots, and that the water so absorbed carries with it substances held in solution, may be easily demonstrated by raising from the soil a vigorously growing succulent plant, washing the earth gently from its roots, and immersing them in a bottle of water containing eosine, red diamond dye, in solution. The water will disappear, and that it is passing upward into the plant will be shown by the red colouring matter creeping slowly up into the stem and leaves. Do all plants then, which can grow on the same soil, require from it the same kinds of food? Experiment

shows that this cannot be the case. If a pea and a plant of wheat grow side by side, and if both be gathered and burned, the ashes of the wheat will be found to contain a large proportion of silica or flint, which served to strengthen its straw, while those of the pea will be found to afford scarcely any of this earth. The water of the soil must have brought a certain quantity of silica to the roots of the pea as well as to those of the wheat, but by the former plant it was rejected as useless, while to the latter it was absolutely necessary. It becomes therefore an interesting question whether the roots themselves have the power of selecting from the soil what is required by the plant, or whether they absorb all matters indifferently, and leave to the other parts of the plant the office of selecting the most proper kinds of food.

A brief discussion of the manner in which substances dissolved in water pass through animal and vegetable membranes will throw some light on this question.

If in a bag of animal membrane, say the lining membrane of a turkey's crop, a mixture of sugar, salt, dissolved gelatine and thin, boiled starch, be tied up and the whole set to float in a pail of water, it will be found, after the lapse of some hours, (a) that the membranous bag is fuller than at first, water having entered it; (b) that some salt and some sugar have passed out through the membrane so that the water on the outside has become just as sweet and just as salt as the liquid within the bag; but (c) that no gelatine and no starch can be detected outside the bag. From the results of many such experiments, varied in countless ways, it is now known that crystalloid substances, such substances as will

crystallize, e.g., sugar and salt, will pass through a wet membrane to mix with water on the other side, while water will come through in the opposite direction to dilute the strong solution, and that this will continue until the solutions on opposite sides of the membrane are of equal strength. It is also known that colloid substances, such as form a jelly with water, e.g., gelatine and starch, will not pass through a membrane. This passage through the membrane, called osmose, does not depend on the vitality of the membrane, which, indeed, in the case supposed, is dead, and which might be inorganic; and the membrane exercises no selective power, all crystalloids pass through it indifferently, and colloids never pass.

So the roots of plants, apparently of all plants indifferently, transmit to the interior of the plants whatsoever crystalloid substances the soil waters bring, and continue to do this until each crystalloid is of equal strength of solution in the sap and in the soil water. If the plant removes one ingredient by consuming it, the soil water continues to provide it, as fast as removed, until the soil itself is exhausted. If the plant uses none of it, equilibrium is soon established between the sap within and the soil water without, and no further interchange of that particular substance is effected. The selective power, then, lies not in the thin membranes that constitute the walls of the delicate cells at the extremities of the roots, but in the whole economy of the growing plant.

Similar considerations throw light on the excretive power of roots. Plants produce various crystalloid substances that are dissolved in their sap. Such substances will be transmitted outwardly, to be retransferred inwardly when they have been chemically

changed by acting on substances outside the plant. A demonstration of the excretion of organic matter is furnished by the fact, that when grain is made to sprout in powdered chalk, after germination has taken place, a part of the chalk (calcium carbonate) is found to be converted into calcium acetate; acetic acid (vinegar) having been produced in the young plants and given out by their roots to combine with the lime. Rootlets growing on litmus paper mark it with red lines, and plants growing in a layer of sand on a marble slab etch a tracing of such roots as reach it on the polished surface.

In strict accordance with the laws of osmotic transfer is the fact that chemical substances which have entered the plant in combination with other substances, and have been separated from them in the plant, may be then transferred outwardly, and there undergo such chemical changes as may fit them to be re-transferred inwardly. Silica alone cannot be dissolved in water, but when it combines with potash, soda, or other alkaline substances, in certain proportions, it becomes soluble, and in this state it enters into the vessels of plants. Silica however requires nearly half its weight of potash or soda to render it soluble, and on examining the ashes of ripe wheat, it is found that the quantity of silica which they contain is four times that of their alkaline matter; or that there is present in the ripe plant only half the quantity of alkali required for the solution of the silica which it contains. It is evident therefore that a portion of potash or soda has been separated from the silica with which it was combined, and has been expelled, and perhaps this process may take place repeatedly, so that a small quantity of alkali may be the means of introducing much silica into the straw of wheat.

An explanation of the well known benefits of a rotation of crops has been attempted on the supposition that the excrements disengaged from the roots of a plant, must be hurtful to others of the same kind if planted in the same soil, while on the other hand they might be nutritive to plants of other kinds. Thus if the roots of a pea be placed in water, they communicate to it in time a brown color, in consequence of gummy secretions being thrown off from the plant; and if, after the water has thus been filled with excrements, another plant of the same kind be placed in it, it will not flourish; but if, instead of a second pea, we place in it a plant of wheat, this will grow luxuriantly and take from the water a part of the matter previously deposited in it. In the same manner, the soil in which any species of vegetable has long been cultivated may become surcharged with its excrements and the substitution of some other crop, which can free the soil from these, may be rendered necessary. But the latest experiments and observations on this subject seem to show that the organic excretions of plants have practically little effect on their culture, and that the extent to which they remove mineral matter from the soil is really the principal cause which renders the soil unsuitable to them. This we must consider under another division of our subject.

#### § 4. *The Stem.*

That the water absorbed by the roots is carried upwards into the stem, is evident from a consideration of what takes place when a plant is grown in a solution of eosine as before described. This water in its progress becomes more or less mixed



with the fluids existing in the plant. In consequence of this intermixture, and probably also of changes effected by the agency of the cells and vessels through which it passes, the sap of trees, even in the lower part of the trunk, differs much from the water which the roots are sucking from the soil. Thus in spring, the sap of the maple is rich in sugar, a substance which it could evidently not obtain from the water in the ground. The presence of this sugar is due to the fact that many trees store up in autumn a quantity of starch, and possibly other substances, in the cells of their stems and roots; and in order that the starch thus prepared may be rendered useful in advancing the growth of the young leaves, the first process necessary is its conversion into sugar, a change, as will afterwards be seen, very easily effected. In spring, before the leaves are developed, growth is going on very slowly, and the sap not being used in the formation of wood and leaves, is allowed to accumulate in the wood, and when the tree is stimulated by the light and heat of the sun, may be obtained by tapping it. But as soon as the leaves are formed, the sap is rapidly withdrawn to furnish materials for their growth, and for the formation of wood; and for this reason it cannot then be obtained in the same quantity or of the same quality as in early spring.

#### § 5. *The Leaves.*

A leaf, as it appears to the unaided eye, consists of a framework of tough fibres, proceeding from its stalk, and branching over it in every direction; on these are stretched two skins or membranes forming its upper and under sides, and the space between these is filled with soft and pulpy matter. When examined with



the microscope, other structures appear. The surfaces of the leaf, especially the lower one, are found to be perforated with numerous minute openings, communicating with small cavities in its interior; the green matter is found to consist of cells filled with a soft green substance; and the fibres are found to be formed of vessels similar to those of the wood. Into the leaves thus constructed, the sap is conveyed from the stem by means of the stalk and fibres; from these it passes into the cells of the green matter, where it is exposed to the action of the external air, and of the light and heat passing through the outer membranes. Under the influence of these powerful causes of chemical change, the leaf becomes the seat of important processes.

1. A large portion of the water of the sap escapes from the leaves by evaporation and perspiration. Water contained in a vessel in which the roots of a growing plant are placed is gradually drawn up and given out by the leaves, until at length, if not renewed, it becomes altogether exhausted; and then the plant droops and withers, because the leaves are rapidly exhaling its fluids, while the roots are receiving no new supplies. This emission of water proceeds with the greatest rapidity when the plant is exposed to the direct rays of the sun, and in darkness it becomes very slow or ceases altogether. Thus the sun-flower, which, in a sunny day, can give off 30 ounces of water, emits only 3 in a dry night, and none in a dewy one. In consequence of this rapid escape of water, the substances which it held in solution are left in a more concentrated state, and ready to be deposited wherever they are required. The large quantity of water which thus passes through their system also

enables plants to obtain from the soil abundance of many substances which are contained in it in very small quantity, or are with difficulty soluble in water.

*Experiments.*

Exp. 85. Invert a tumbler over some thickly growing herbage on the ground, as a mass of chickweed or some turf. Observe the amount of moisture condensed in the tumbler.

Exp. 86. Pinch a growing leaf gently between two pieces of glass in the sunshine for twenty minutes. Observe the greater amount of moisture given off by the lower side of the leaf, because the lower side has more pores than the upper side.

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It is not easy to determine just how great the amount of water exhaled by the growing plant is. Investigators have been led to discordant results, probably because the amount of transpiration is influenced by many conditions,—by temperature, by the amount of moisture in the soil, by the humidity of the air, and by the amount of sunlight, as well as by the nature, the vigour and the degree of maturity of the plants investigated. As an approximation to the truth it may, perhaps, be said that for every pound of dry material formed by the growing plant it transpires 350 to 400 pounds of water, and that, perhaps, 10 tons of water are evaporated daily from an acre of ground covered with vigorous vegetation.

The powers of the leaves, with reference to water, are not limited to exhalation; in some cases they can also absorb it from the atmosphere, or from the rain and dew which fall upon them. It is thus that drooping plants may be revived by watering their

leaves, and thus that the air plants of China and Buenos Ayres flourish when suspended from the walls and balconies of houses, without any connection with the ground. But the amount of water thus imbibed by such plants as the farmer cultivates is very small.

2. The leaves absorb and decompose carbon dioxide, which, as before stated, exists in small quantity in the atmosphere, and is the principal source of the carbon in plants. If a vegetable be confined in a glass vessel containing air, with the usual proportion of carbon dioxide, or having a little more artificially added, and then placed in the sun, after some time it will be found that a part of the carbon dioxide has disappeared, and that a corresponding quantity of oxygen occupies its place. This change is effected by the leaves, and other green parts of the plant, which, therefore, have the power of absorbing carbon dioxide, decomposing it, retaining the carbon, and expelling the oxygen.

If a handful of parsley be bruised, squeezed into a cup and covered with alcohol for a few hours, an alcoholic extract of chlorophyll will be made, which will appear green by transmitted and reddish brown by reflected light. It is to the presence of this substance, chlorophyll, that leaves owe their colour, and, as before remarked, their power of decomposing carbon dioxide.

This decomposition of carbon dioxide proceeds with rapidity in sunlight; it goes on much more slowly in the shade, and ceases altogether in darkness. Accordingly, during the prolonged sunshine of the summer in arctic and subarctic regions, vegetation advances with extraordinary rapidity. At Alten, in Norway, lat. 70° N., peas have been known to grow in length

3½ inches in 24 hours, and some of the cereals 2½ inches in the same time. At the same place barley ripens twenty days earlier than at Christiana, 10° further south, where also the average temperature of the summer is 6° F. higher.

While leaves absorb and decompose carbon dioxide in the sunlight only, all developing parts of the plant are constantly absorbing oxygen and emitting carbon dioxide; relatively in much smaller quantity, it is true, during daylight, so that this process is then apt to be overlooked. As the latter process goes on in darkness, when the former is wholly arrested, it then attracts attention, but in 15 or 20 minutes of direct sunshine a plant will decompose as much carbon dioxide as it exhales during a whole night.

The decomposition of carbon dioxide by the leaves of plants is most important to their growth, because upon the carbon thus fixed in their structures their strength and solidity in a great measure depend; and as this decomposition can only proceed in the presence of air and light, plants cultivated where these are deficient, become blanched, slender and watery. For the same reason, potatoes and other vegetables, cultivated for the starch and similar substances contained in their roots, are unable to obtain the necessary quantity of carbon, and in consequence produce a crop of inferior quality, when cultivated in the shade or too thickly crowded. It is thus also that where plants can obtain light only in one direction, they grow toward it; for the side next the light being able to fix more carbon, becomes firm and woody, while the other, being soft, extends more rapidly, and hence the stem bends toward the light. From the same cause the wood of trees which have grown in

open ground, is more hard and durable than that of those which have lived in thick forests.

3. The leaves absorb and emit other gaseous bodies beside carbon dioxide. Experiment shows that the leaves cannot absorb nitrogen directly from the air, but that they readily absorb the ammonia and nitric acid floating in it, and, by decomposing these obtain the nitrogen required by the sap. The various odors and perfumes exhaled by many leaves and flowers are all volatile matters, formed in their cells and vessels, and which would probably be injurious if retained.

In the leaves, then, the sap loses much of its water, receives an additional quantity of carbon, and is subject to other changes afterwards to be considered ; thus altered it passes into the vessels of the bark.

#### § 6. *The Bark.*

—The principal office of the inner bark is to apply to the formation of new tissues the substances contained in the thickened sap which it receives from the leaves. For this purpose this fluid is carried downward, adding new matter to the outer surface of the wood and the inner surface of the bark, and penetrating by the medullary rays to nourish the interior of the tree. In this manner it returns to the roots, by whose extremities its waste and useless portions are probably returned to the soil ; and the remainder, becoming mixed with the ascending sap, is again carried upward to the leaves. In some plants, such as the grasses, which have no true bark, the descending sap probably passes through a particular set of vessels, which are mingled among those which carry the ascending sap.

From the very short and general view which we have taken of the nutrition of vegetables, it appears that their food is obtained from the water contained in the soil, and by the leaves from the atmospheric air; that the substances obtained from both these sources are united in the leaves; and that they there undergo changes fitting them for being converted into the various matters which are found in the roots, stems and fruits of plants. The nature of these changes, and of the substances which result from them, are next to be considered

## CHAPTER VII.

### ORGANIC COMPOUNDS PRODUCED BY PLANTS.

#### §1. *Organic and Inorganic Substances.*

All the forms of matter which we observe on the globe, may be divided into two great classes, *Organized* and *Unorganized* matter. To the latter belong all those rocks, waters, metals, and other substances, which neither are nor have been the seat of life, and which constitute the mass of our earth. To the former belong the bodies of animals and plants, and the various substances composing them, such as flesh, blood, starch, wood, etc. These compounds being produced by organized bodies, those possessing life and organs for its maintenance, are hence properly named organic substances.

Organic substances are all compound, and when exposed to air and moisture, they decay and, except a small quantity of fine dust, gradually disappear into the air. When burned or exposed to heat, they are decomposed, and some, such as fat, gum and sugar, are entirely dissipated in a gaseous state, while others, as wood and lean beef, leave a small quantity of ash. This ash, as will be afterwards seen, is an essential and necessary part of vegetable structure, and consists of substances which the plants have taken from the soil, and which are distinguished as inorganic. By the mere application of heat in presence of air, or by burning, we can thus separate the mass of any organized body, a plant for instance,



into two groups of substances,—the *organic*, which usually constitutes the greater part of the mass, and which burns away, and the *inorganic*, or earthy part, which remains as the ashes. The inorganic matter contained in the ashes of plants, though by no means of secondary importance in agriculture, may be left for the present unnoticed, while we attend more particularly to their strictly organic part, reserving the ashes for a subsequent chapter.

### § 2. *Organic Part of the Plant.*

It was before stated that all the known varieties of matter consist of between sixty and seventy simple substances; but it is a still more remarkable fact, that plants of every description, with all their endless variety of appearance and properties, consist for the most part of but four of these elements, carbon, oxygen, hydrogen, and nitrogen. The same remarks apply, with equal truth, to animal substances.

The proportions of the constituents of plants vary somewhat widely in different plants, and even more widely in different parts of the same plant. Tobacco contains three times as much ash as an equal weight of hay, and the grain of wheat six times as much nitrogen as the straw. But a first rough approximation to the truth is made by the statement that the plants cultivated by the farmer, when thoroughly dried, consist of about 47% C, 40% O, 5% H, 2% N, and 6% ash. More exact statements will be found in the table page 141.

It will be observed that carbon preponderates in the composition of the vegetable. This substance is never absent from organic compounds. It is to its presence that these substances owe that liability to



char when exposed to heat, by which the chemist often distinguishes organic from inorganic substances. Carbon, as already stated, is neither volatile nor fusible at the highest temperatures of combustion, consequently when a substance containing much carbon is exposed to a high temperature with limited access of oxygen, the associated substances are burned or volatilized, leaving some or all of the carbon behind to reveal itself by its intensely black colour.

It thus appears that three of the four elements which chiefly constitute the solid structure of animals and plants, are, in their pure state, invisible gases, and the remaining one is identical with ordinary charcoal; yet into how great a variety of beautiful forms and valuable products are they transmuted by nature, and how interesting and instructive must be the study of the ways in which these wonderful processes are effected. This becomes still more remarkable when we add that by far the larger part of the mass of vegetables consists of substances composed of three of these elements only—carbon, oxygen and hydrogen. Of this nature are wood, starch, sugar, etc. The substances containing nitrogen, or the nitrogenized substances, are in comparatively small quantity in plants, though of vast importance, since they are those on which the subsistence of animals chiefly depends; for while the organic part of the plant consists chiefly of non-nitrogenized matter, that of the animal consists principally of the nitrogenized.

### § 3. *Organic Substances Arranged in Groups.*

We have seen that carbon dioxide, water, ammonia and other substances, which form the food of plants,

are taken into their cells and vessels, and constitute the raw material which affords the carbon, oxygen, hydrogen and nitrogen required for the formation of their tissues and products. Nothing in nature is more wonderful than the processes of organic chemistry, by which the plant succeeds in forming out of so few elements that almost endless variety of woods, resins, oils, gums, acids, sugars and other matters which are contained in plants.

It is to the presence of different compounds of these descriptions that vegetables owe the diversity of tastes, odours, colours, and of nutritious, poisonous, or medicinal properties, which we find in different plants and in different parts of the same plant; a diversity so great that we can scarcely help considering every vegetable to be endowed with the power of arranging in ways peculiar to itself, the simple substances contained in its food.

To examine in detail all this vast variety of vegetable products, and endeavour to discover the causes of their production, would form an interesting study; but it would lead us far from the applications of chemistry to common agriculture, and would involve us in some of the most difficult questions in the science; questions, many of which are yet unanswered, or but very imperfectly understood. There are, however, some of these substances so generally diffused among plants, or so valuable to man, that they must receive our attention, if we would wish to know of what the produce of our fields consists, how it is prepared, or how it can be best obtained. We may for our present purpose divide these substances into two groups, the Non-nitrogenized and the Nitrogenized, again subdividing the Non-nitrogenized into three

subordinate groups, viz., carbohydrates, acids and fatty or oily substances.

#### § 4. *Carbohydrates.*

The greater part of the substance of vegetables consists of compounds destitute of nitrogen, containing, therefore, only three of the four organic elements. Of these substances we may notice :

1. *Cellulose or Woody Fibre*, so named because wood is almost wholly composed of it. It is present in the stems, roots and leaves of nearly all plants, forming the sides of their cells and vessels ; and hemp, flax and cotton consist of cellulose nearly in a state of purity. When the wood of different trees is analyzed, it is found to vary somewhat in its composition, probably because the cells and vessels of wood become incrustated or partially filled with other matters which cannot be easily separated from the true woody fibre. It is, perhaps, for the same reason that the composition of cotton, pith and the cellular matter of soft vegetables is found to differ slightly from that of the wood of trees.

In pure cellulose, however  $C_6H_{10}O_5$ , the quantity of oxygen is 8 times that of the hydrogen ; or, in other words, these two elements are in the *proportions required to form water* ; so that woody and cellular matter may be viewed as composed of charcoal and water ; though it is evident that the water or its elements, which thus compose more than half the weight of wood, must be in a very different state from that in which this fluid is usually found. For this reason it is that this group of substances is designated by the term carbohydrates.

2. *Starch*.—This substance is, like wood, contained

in nearly all plants, but, while wood is the material of the cells and vessels, starch is at particular seasons stored up as a reserved stock of food, to be employed when other supplies fail, or when a growth more luxuriant than ordinary is required. Many plants whose stems die in autumn, form large roots or underground stems, containing matter fitted to send forth and nourish vigorous shoots in spring, and this matter very frequently consists in great part of starch. The tubers of the potato, for instance, are constructed of cells, each of which contains several little grains of starch, destined, if not used as food by animals, to be drawn off by the vessels of the sprouting "eyes" in spring. Grains of all kinds, and many other seeds, contain large quantities of starch, destined to furnish the first food to the seedling plant. Thus wheat contains from 59 to 77 per cent. of starch; barley 67 to 70; oats, 70 to 80; rice 84 to 85. Starch therefore forms a large part of bread, and most other kinds of vegetable food; in using which we are applying to the promotion of our growth what plants have prepared for theirs.

Starch, when pure, is colorless and tasteless; it is not dissolved by cold water, but with hot water it forms a jelly which by prolonged boiling becomes clear, the starch having been rendered soluble. The composition of starch is indicated by the formula  $C_6 H_{10} O_5$ , the same as that of cellulose.

3. *Gum*.—Of this substance cherry gum and gum Arabic are good examples. It is found in the state of mucilage in the sap of all plants, and in nearly all the roots and seeds used for human food. Gum dissolves in water, forming mucilaginous solutions; that obtained from different plants differs in solubility, some

varieties being soluble only in hot water, others in cold, and others forming a kind of jelly. The composition of gum is the same with that of starch,  $C_6 H_{10} O_5$ .

4. *Sugar*.—The most familiar example of this substance is common cane sugar, sucrose, which is found abundantly in the sugar cane, maple, Indian corn, beet, and various other plants. The composition of cane sugar differs little from that of starch and gum. It is  $C_{12} H_{22} O_{11}$ .

In a number of plants, varieties of sugar are found, differing somewhat in chemical constitution from that of the cane. The most important of these is *grape sugar*, glucose, which contains more of the elements of water than any of the substances before noticed, its composition being  $C_6 H_{12} O_6$ . This sugar is less soluble in water and less sweet than the common variety. It is found in honey, in germinating seeds, in fermented liquors, in the grape, gooseberry, apple, plum and most other fruits. It is therefore especially the sugar of fruits and of germinating seeds, as cane sugar is especially that of the general sap.

Before proceeding further, we may pause for a little to consider some of the *mutual relations* of the four substances which have just been described. They are produced by vegetables in greater abundance than any other substances, and are concerned in most of the changes which take place by the agency of vegetation. That they may be more readily obtained by all plants, they are composed of carbon, oxygen and hydrogen alone, so that whenever carbon dioxide and water are present, the materials for their formation can be obtained; and these, as we have already seen, may be found in every place where vegetation can subsist.

So simple are the relations of these carbohydrates

to carbon dioxide and water, the universal food of plants, that it is easy to imagine the general method of transformation by which the deoxidation of  $\text{CO}_2$  and of  $\text{H}_2\text{O}$  gives rise to these substances. Boussingault has suggested that  $\text{CO}_2$  and  $\text{H}_2\text{O}$  are deoxidized together, the former losing one-half of its oxygen and the latter the whole. Thus  $\text{CO}_2 + \text{H}_2\text{O} = \text{CO} + \text{H}_2 + \text{O}_2$  of which we may suppose the  $2\text{O}$  to be disengaged. Then six times the residue would be glucose,  $\text{C}_6\text{H}_{12}\text{O}_6$ . Glucose less a molecule of water would be cellulose or starch or gum, for  $\text{C}_6\text{H}_{12}\text{O}_6 - \text{H}_2\text{O} = \text{C}_6\text{H}_{10}\text{O}_5$ ; and two molecules of glucose less one of water would be sucrose  $2(\text{C}_6\text{H}_{12}\text{O}_6) - \text{H}_2\text{O} = \text{C}_{12}\text{H}_{22}\text{O}_{11}$ .

It must not, however, be supposed that the above or any similar scheme certainly reveals the detailed processes of nature; for these are as yet quite unknown.

While the carbohydrates all consist of the same elements, they contain them in the same or nearly the same proportions. In this respect we may almost regard them as only one substance, capable of assuming several different forms; in its soluble states of gum and sugar circulating in the sap and supplying nourishment to every organ, and in its more-insoluble forms stored up as starch for future nourishment or fashioned into tough woody walls of cells and vessels.

That these substances, thus nearly related, may be changed from one form to another, that sugar may be converted into wood or starch, and gum into sugar, and *vice versa*, we have abundant proof in many common processes. If barley be moistened and thrown into a heap, as in the process of malting, as soon as it has sprouted we find a great part of its starch converted into sugar; the sugar of the beet or of maple

sap, when these plants begin to grow in spring, soon disappears and becomes converted into woody stems and leaves; and when a potato is planted and begins to grow, its starch furnishes the material for its stems and foliage, after having first been taken up in the sap in the form of gum and sugar.

Some of these changes may be produced by art, and by examining how this is done, we may be better able to understand how they occur in the living plant. They may be effected:—

1. *By Heat*.—If sawdust be carefully washed, then dried in an oven till it becomes crisp, and afterwards ground, the wooden flour thus produced, if boiled in water, forms a jelly like that from starch. By merely applying heat and moisture, we can thus convert woody fibre into starch. Again, starch when exposed to a heat below  $300^{\circ}\text{F}$ . becomes yellow or brown, and in this state is soluble in cold water, and in other respects has the properties of gum. Starch changed in this way is called British gum, and forms a good substitute for gum Arabic. Chemically, British gum is dextrin,  $\text{C}_6\text{H}_{10}\text{O}_5$ . Lastly, in the manufacture of British gum, a portion of the starch is sometimes changed into sugar. Heat, therefore, is capable of transforming starch into gum, and gum into sugar.

2. *By Acids and Alkalies*.—If to a quantity of fine sawdust or linen rags, we add more than its weight of sulphuric acid, and rub the mixture in a mortar, the wood or linen will be converted into jelly and then into gum. If to the gum thus produced we add more sulphuric acid, and a quantity of water, and allow it to stand for some time, the gum will be found changed into grape sugar. Any of the varieties of wood, starch, or gum, may thus be converted into



sugar; and in France potato starch thus transformed is employed to some extent in the manufacture of brandy and fermented liquors. 100 lbs. of starch mixed with 600 of water, and 10 of sulphuric acid, by boiling for seven or eight hours, produce about 112 lbs. of grape sugar.\*

*Cane* sugar may also by the action of acids be readily changed into *grape* sugar; and it is for this reason that fruits preserved in sugar often become candied. The vegetable acids of the fruit convert the cane sugar into grape sugar, and the latter, being less soluble, crystallizes in little lumps.

Alkaline substances are also capable of effecting some of these transformations. If sawdust be boiled in a strong solution of pure potash, a portion of the woody fibre will assume the properties of starch.

Since we can so easily, by artificial means, produce these transformations, it cannot be doubted that they can be still more readily effected within living plants. Human art can, however, imitate only a part of the processes of this kind which are known to take place in vegetables. We can change wood into starch, and starch into gum, and gum into sugar; but chemistry is altogether unable to reverse the process, and convert sugar back again into wood.

The plasticity of these compounds of carbon and the elements of water, is not, however, limited to mutual transformations. By various kinds of *decomposition* they can be changed into other substances, such as alcohol and vinegar. One of the most common changes of this kind is *fermentation*. When to a decoction of malt, or to the juices of sweet fruit, we

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\*A process similar to this is now extensively employed in making glucose for the use of confectioners.

add a little yeast, carbon dioxide begins to escape, and in time the grape sugar contained in these liquids is found to be changed into *alcohol* or spirit,  $C_2 H_6 O$ . In this case  $C_6 H_{12} O_6 = 2 (C_2 H_6 O) + 2 (CO_2)$ . One of grape sugar yields two of alcohol and two of carbon dioxide. The carbon dioxide escapes from the fermenting liquid in bubbles, and the alcohol remains in the water. By further exposure to the air the alcohol thus produced absorbs a portion of oxygen from the atmosphere, and is changed into vinegar. Thus alcohol together with oxygen becomes acetic acid and water;  $C_2 H_6 O + 2O = C_2 H_4 O_2 + H_2 O$ .

These artificial modes of transforming wood, starch and vinegar, though they may not show us exactly the ways in which these changes take place in plants, are sufficient to give an idea of some of the means by which they may be effected. We may now consider another class of bodies found in most plants, the acids.

### § 5. *Vegetable Acids.*

1. *Acetic Acid or Vinegar* is one of the most abundant. It is present in the juices of many plants, is produced in the germination of seeds and by the fermentation of dead vegetable matter. The composition of vinegar is given by the formula  $C_2 H_4 O_2$ , so that like grape sugar it contains equal proportions of carbon and the elements of water. In conformity with this similarity of composition, a solution of cane sugar with a little vinegar added to it, when exposed to the air for some time, becomes changed into a solution of vinegar. Most of the vegetable acids, however, contain oxygen in excess of the amount necessary to form water with the hydrogen present. This is the case in the acids hereafter enumerated.

2. *Tartaric Acid* is composed of  $C_4 H_6 O_6$ , containing therefore proportionally more oxygen, and less hydrogen, than the acetic. It is contained in sorrel and in some berries, and, in combination with potash, abounds in the grape. The hydrogen-potassium-tartrate,  $HKC_4 H_4 O_6$ , obtained from the latter fruit, is the well known cream of tartar.

3. *Citric or Lemon Acid* differs little in composition from the last, ( $C_6 H_8 O_7$ ). It gives acidity to the lemon, orange, cranberry and strawberry.

4. *Malic Acid* differs slightly in composition from the tartaric. It is  $C_4 H_6 O_5$ . It gives their sourness to the unripe apple and plum.

5. *Oxalic Acid* is found abundantly in many plants, usually in combination with lime or potash. It exists in the sorrels, in rhubarb, and plentifully in many of the lichens which grow on trees and stones. Oxalic acid consists of carbon, hydrogen and oxygen, in the proportion of  $C_2 H_2 O_4$ .

These and many other acids occur in greater or less abundance in most plants; and though they do not constitute an important part of their bulk, they are of some consequence. They communicate to many fruits and other articles of food an agreeable acidity. They combine with and render soluble and otherwise suitable for plants, many of the earthy substances which are found in them. They serve, in the modes before noticed, to effect changes in the substances contained in the tissues or sap; for example, in converting starch into sugar. And lastly, they are themselves capable of being transformed into various useful products, as we often see to be the case in the conversion of a sour unripe fruit into a sweet ripe one. In this change the acid present in superabundant

quantity in the unripe fruit, and causing it to be unpalatable and unwholesome, is converted into grape sugar, and the fruit is thus rendered agreeable to the taste, and nutritive.

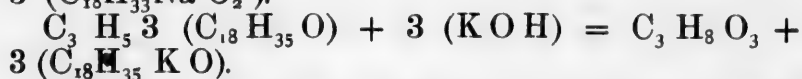
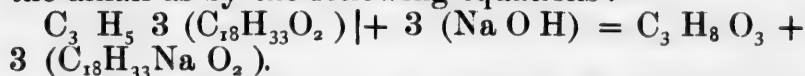
### § 6. *Oils and Fats.*

Two kinds of oils are found in plants, the volatile and the fixed oils. The volatile oils, present usually in small quantities in plants, and, therefore, although important as giving odours and flavours to vegetable products, of slight importance agriculturally, cannot here be considered. But the fixed oils and the fats, which are distinguished from the volatile oils by leaving a permanent grease stain on paper, are of greater importance, and must receive brief notice.

The oils and fats produced by vegetables are numerous; but they are somewhat similar in chemical composition and may be sufficiently represented by two of their number; one oil, oleine, and one fat, stearine. Oleine is the chief ingredient in olive oil; and stearine, an abundant constituent of many vegetable oils and fats, is found nearly pure in mutton tallow. Oleine is represented by the formula  $C_3 H_5 3 (C_{18} H_{33} O_2)$ ; and stearine is  $C_3 H_5 3 (C_{18} H_{35} O)$ . When these substances are distilled in a current of highly heated steam, each molecule reacts on three molecules of water, as indicated in the subjoined equations,  $C_3 H_5 3 (C_{18} H_{33} O_2) + 3 (H_2 O) = C_3 H_8 O_3 + 3 (C_{18} H_{34} O_2)$ , and  $C_3 H_5 3 (C_{18} H_{35} O) + 3 (H_2 O) = C_3 H_8 O_3 + 3 (C_{18} H_{36} O)$ . The common result of the two reactions,  $C_3 H_8 O_3$ , is the interesting substance glycerine, familiar to us as a colourless, viscid, sweet liquid. The  $C_{18} H_{34} O_2$  of the first reaction is known as oleic acid, and the  $C_{18} H_{36} O$  of the second is named by the chemist

stearic acid, is known in trade by the designation Belmont sperm, and is used in the manufacture of Belmont sperm candles.

When oleine or stearine is heated with a solution of sodium hydroxide or potassium hydroxide one molecule of the oil or fat reacts with three molecules of the alkali as by the following equations:—



Glycerine, it will be observed, is produced in each case; and, in the first instance, three molecules of sodium oleate, and, in the second instance, three molecules of potassium stearate are formed. These are soaps. The first is the soap that results from boiling olive oil and caustic soda together, and is known in trade as Castile soap. The second is a soft soap such as the housewife makes when she boils together domestic grease, consisting chiefly of stearine, and the lye of wood ashes, which contain much K O H. Potash soaps are soft; soda soaps are hard. Hence, when the housewife wishes to make hard soap from her soft soap, she stirs into the soap, while still hot, some salt, and interchange of elements takes place as by the following equation:  $\text{C}_{18}\text{H}_{35}\text{KO} + \text{NaCl} = \text{C}_{18}\text{H}_{35}\text{NaO} + \text{KCl}$ . A sodium soap, or hard soap, and potassium chloride are thus formed.

### § 7. *Nitrogenised Substances.*

These, though present in much smaller quantity than the non-nitrogenized constituents of the plant, are of vast importance both to the plants themselves and to the animals which feed on them. In the plant

they appear to determine all the vital changes by which the other substances are produced ; and to the animal they are the materials out of which alone its most important tissues can be formed.

1. If we take a small quantity of the dough of wheaten flour and wash it on a linen or muslin rag so as to remove the starch which forms a large constituent of the flour, we find remaining on the cloth a substance of a remarkably sticky and tenacious character. It is known as the *gluten* of wheat, and it is to this substance that the flour owes its capacity for constituting a tenacious paste and for forming raised bread. It is a nitrogenized substance, insoluble in water, but soluble in acids and alkalies ; and is similar in composition with the flesh of animals. It constitutes from ten to twenty per cent. of the grain of wheat. Other grains contain this substance, but in less quantity than that of wheat.

2. In Indian corn a similar substance, or rather a modification of the same, occurs, and has been called *zein*. Another similar substance occurs in considerable quantity in peas and beans, and is named *legumin*.

3. If the juices of many succulent plants, as of the tubers of the potato, are heated to the boiling point, flakes of curdled matter separate from the fluid, and are found to consist of the substance *albumen*, with which we are familiar in the white of egg. This substance, unlike gluten, is soluble in water, though it curdles and becomes insoluble when heated. It is thus suited for circulating in the sap of plants ; and as glutinous and albuminous matters seem to be mutually convertible, they may be regarded as related to each other in the same manner in which starch is related to sugar or gum.

All of the above mentioned nitrogenized substances contain, in addition to carbon, hydrogen, oxygen and nitrogen, a small portion of sulphur, which seems to be a necessary ingredient in their composition.

Approximately the several nitrogenous substances named above consist of 54% carbon, 7% hydrogen, 16% nitrogen, 22% oxygen, 1% sulphur. Some of them also contain phosphorus, but in small quantity only, seldom amounting to one-half of one per cent.

Their composition is not so well understood as to enable us to express it in definite, generally accepted formulæ.

#### § 8. *Proximate Analysis of Plants.*

It may be said of all plants cultivated by the farmer that they chiefly consist of water, cellulose, soluble carbohydrates, acids, oily or fatty matters, and nitrogenous materials. Either essential to the composition of these substances, or entangled with them in the process of growth, is a small percentage of ash, to the consideration of which attention must be directed in the next chapter. The proportions of these substances differ much in different plants, and still more in different parts of the same plant, as will appear clearly on examination of the table, page 141, which gives in columns 5 to 10 inclusive, the results of a proximate analysis of the chief agricultural products.

Columns 1-5 inclusive, of the same table, give the result of the ultimate analysis of the same substances, column 5 belonging to both analyses. An ultimate analysis differs from a proximate analysis in this respect, that the ultimate analysis gives the weight of each element in a substance, while a proximate



analysis gives the weight of each separable compound in it.

*Example.*

136. See what differences there are between the ultimate analysis given in the table and the results you could find from the proximate analysis on the supposition that the fibre mentioned is cellulose, that the soluble carbohydrates are starch, that the oil is oleine and that the composition of the nitrogenous substances is given correctly on page 137.

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In this table the quantity of nitrogenized matter expresses very nearly the flesh-producing value of the several substances when used as articles of food; and in this respect such facts are not only important in relation to the nature of plants, but in relation also to their use as food for men and animals. All the edible substances afforded by the vegetable kingdom may be grouped under two heads—the heat-and-work-producing and the flesh-producing. Under the former come starch, sugar, gum and oil. These substances, by their combustion in the body, keep up animal heat, maintain muscular energy, and prevent waste and thinness. Animals fed on such substances and not exposed to cold, tend to accumulate fat; on the other hand, the consumption of such food enables them to endure cold. To the second class belong gluten, albumen and legumin, which afford the material of flesh and sinew. The scientific selection of food for animals depends in great part on the study of the relative amounts of these two kinds of food in different substances, and in duly proportioning these accordingly. The relative amounts of curd and

cream produced by milch cattle may also be influenced in the same way. But these are subjects too extensive to be considered in this place.

We may close this notice of the organic matters contained in plants by stating briefly the relations which they bear to the food and structure previously referred to.

### § 9. *Conclusions as to the Food of Plants.*

The organic food of plants consists in part of gaseous or aeriform substances, and in part of substances not aeriform, but fixed. The gaseous part of the food may be absorbed by the leaves directly from the air, or by the roots from the soil; in which latter case it is usually taken up through the medium of water, in which it has become dissolved. The fixed part of the food can be obtained only from the soil, and only by the roots, and by these only in a state of solution in water. Of the elements actually found in the plant, those that constitute its organic or combustible part may be obtained either in a gaseous or fixed state, either from the air or from the soil; those that constitute its ashes or incombustible part, as we shall find, only from the soil.

In respect to both these classes of substances, the root and the soil are the most important practical subjects of consideration; since the air is alike in its composition, or nearly so, at all times and places, and cannot in this respect be regulated by the farmer. Still, as the leaves absorb food from the air, whatever gives it the largest amount of healthy leaf will enable the plant to do this most effectually, and sufficient exposure to air and light are also absolutely necessary. The farmer, by taking proper care of the root and the

soil, thus provides also for the proper action of the leaf and the air.

In respect to the particular elements of the organic part of the food of plants, while it is useful to have in the soil organic matters yielding carbon dioxide, it is more essential to have substances yielding nitrogen either as ammonia or nitric acid. For this reason the richer animal manures are justly held to be of great importance in agriculture; while it is also of the first importance that such manures should be applied to plants in their young state, that they may early form large and healthy leaves and roots, and may thus be able to avail themselves of the stores of carbon dioxide and ammonia afforded by nature. It is thus to be observed that while the organic part of the food of ordinary plants may be furnished by the air and rain, yet the more important cultivated plants require more than this in order that they may yield large crops; and further, that the small and starveling plants of a poor soil have not sufficient root or leaf freely to avail themselves of the liberal stores of nature. Hence, though strictly organic manures may not be so important to plants as those which supply the material of the inorganic part, they are still of great value.

In the most favorable circumstances in our climate one acre of land under cultivation does not assimilate in a year more than 3,000 lbs. of carbon, 3,000 lbs. of oxygen, 400 lbs. of hydrogen and 100 lbs. of nitrogen. Indeed a good crop of oats assimilates only 2,500 lbs. of carbon, an almost equal amount of oxygen, 350 lbs. of hydrogen, and 50 lbs. of nitrogen.

COMPOSITION OF THE MORE IMPORTANT PLANT PRODUCTS, GIVEN IN POUNDS  
PER 1000 OF THE MARKETABLE PRODUCE.

	Ultimate Analysis (water omitted).				Proximate Analysis (including ash).					Ash Ingredients.											
	Carbon.	Oxygen.	Hydrogen.	Nitrogen.	Ash.	Water.	Fibre.	Soluble Carbohydrates.	Oils.	Nitrogenous Substances.	Potash.	Soda.	Lime.	Magnesia.	Silica.	Oxide of Iron.	Chlorine.	Sulphuric Acid	Phosphoric Acid	Total Ash.	
GRAINS AND SEEDS.																					
Wheat.....	390	372	54	20	20	144	34	676	16	130	6.26	.64	.64	2.48	.38	.14	.10	.14	9.22	20	
Barley .....	388	378	53	15	23	143	85	657	25	90	4.83	.80	.53	1.91	6.50	.20	.25	.46	7.52	23	
Oats .....	398	357	55	17	30	143	99	585	57	116	4.68	.78	1.11	2.19	13.95	.21	.21	.48	6.39	30	
Rye.....	390	376	54	17	20	143	35	692	20	110	5.82	.88	.80	2.34	.54	.14	.10	.14	9.24	20	
Maize.....	402	362	56	15	21	144	52	643	66	95	5.84	.82	.52	3.15	.34	.17	.04	.31	9.81	21	
Peas .....	400	343	54	35	25	143	92	518	25	222	10.30	.78	1.35	1.90	.20	.20	.37	1.08	8.82	25	
STRAW.																					
Wheat.....	363	386	50	3	55	143	504	317	15	21	6.32	.88	3.19	1.37	37.95	.39	.61	1.37	2.92	55	
Barley .....	363	386	50	3	55	143	508	313	15	21	10.67	2.25	4.29	1.38	29.75	.72	1.43	2.04	2.47	55	
Oats .....	367	385	51	4	50	143	415	396	20	26	10.15	3.20	3.70	1.90	24.75	.80	1.80	1.65	2.05	50	
Rye.....	372	398	52	3	32	143	553	276	13	15	5.95	1.05	2.45	.98	18.56	.35	.57	.60	1.49	32	
Maize.....	371	393	51	5	40	140	415	403	11	31	13.20	.40	3.99	2.06	14.23	.24	.87	1.99	3.02	40	
Peas.....	376	378	52	11	40	143	410	361	20	66	8.73	2.12	15.18	3.10	2.29	.73	2.45	2.29	3.11	40	
HAY.																					
Timothy.....	381	363	53	15	45	143	231	496	31	99	12.91	1.22	4.19	1.62	15.97	.32	2.25	1.71	4.81	45	
Red Clover....	365	334	51	21	62	167	362	302	33	136	20.03	.99	21.14	7.75	1.30	.62	2.29	1.86	6.02	62	
GREEN FODDER.																					
Maize.....	77	78	10	2	11	822	49	113	5	11	3.42	.22	.82	.94	2.63	.08	.17	.41	2.31	11	
Rye.....	119	114	17	5	16	729	80	163	10	18	6.11	.10	1.16	.49	5.04	.29	.29	.19	2.33	16	
Oats.....	82	79	11	4	14	810	68	93	5	24	5.32	.46	.94	.45	4.51	.22	.56	.38	1.16	14	
ROOTS AND TUBERS.																					
Potatoes.....	110	113	15	3	9	750	11	215	3	21	5.45	.15	.22	.41	17.08	.24	.24	.63	1.65	9	
Carrots.....	64	64	9	3	10	850	18	114	2	16	3.71	2.08	1.09	.62	20.10	.49	.49	.69	1.12	10	
Mangolds.....	51	51	7	2	9	880	10	97	1	12	4.70	1.33	.41	.45	30.07	.59	.59	.30	.85	9	
Rutabagas.....	55	54	8	3	10	870	12	100	1	17	5.12	.67	.97	.26	.05	.04	.51	.85	1.53	10	

## CHAPTER VIII.

### THE ASHES OF PLANTS.

#### § 1. *Table of Plant Analysis.*

We have already seen that the combustible or organic part of the plant, at least in the kinds cultivated by the farmer, largely preponderates over the ashes. We are not on that account, however, to suppose the materials of the ashes of small consequence to the plant; on the contrary, experience proves that they are of the utmost importance; and since they can be obtained only from the soil, and not at all from the air, their presence in the ground must be closely connected with its fertility or barrenness. The table, page 141, compiled from various sources, representing the results of chemical analyses of plants and their ashes, will enable us to illustrate these points.

#### § 2. *General Deductions from the Table.*

An examination of the foregoing table suggests at once several important truths.

First.—The chemical relations of the ash-ingredients are manifold. Two are alkalies, potash and soda; two are alkaline earths, lime and magnesia; two are oxides of heavy metals, oxide of iron and oxide of manganese; two are acids, sulphuric acid and phosphoric acid; one, silica, and one, chlorine, differ widely in chemical relations from each other and from all other ash-ingredients.

Secondly.—As each ash-ingredient is present in the ashes of each plant given in the foregoing table, in

plants that differ botanically so widely as wheat, peas, potatoes and turnips, it is difficult to avoid the conclusion that each substance enumerated has relation to the functions of plants as plants, and not merely to the peculiar functions of each kind of plant.

Thirdly.—Yet that the varying proportions of ash-ingredients have something to do with the peculiar functions of each kind of plant is evident by observing the resemblances in the ashes of plants of allied species and the differences in those of widely diverse species. Compare, for example, the amounts of lime and of silica in the straw of wheat, barley and oats; and contrast with the amounts of these substances in pea straw.

### § 3. *Essential Ash-Ingredients.*

Are all the substances named above essential to the development of plants ?

Many experimenters have shown by growing plants in soils artificially prepared, or in water, that potash, lime, magnesia, phosphoric acid and sulphuric acid are essential to the growth of plants. Of soda it is found that the proportion is very variable; in some cases the amount is almost imperceptible; in other cases, with plants of the same kind, it is present abundantly. The conclusion to which we are driven, as stated by Johnson ("How Plants Grow"), is "that soda is never totally absent from plants; that, if indispensable, but a minute amount is requisite; and that the foliage and succulent portions of the plant may include a considerable amount of soda that is not necessary to the plant, that is, in other words, accidental." A precisely similar statement may be made of chlorine.

Oxide of iron in minute quantity is essential to the growth of plants, although the amount is so small as to be discoverable in some instances only by sensitive tests.

Silica is found in the ashes of all plants grown in ordinary conditions, and is very abundant in the grasses, accumulating in them centrifugally; that is to say, it is most abundant in the cuticle of the stem, in the leaves, and especially in their tips, and in the husk of the grain. But recent investigations have seemed to indicate that much of this silica is accidentally present, and Knop has gone as far as to say: "I believe that silica is not to be classed among the nutritive elements of the grasses." It is difficult, however, to receive this statement, in view of the invariable presence and comparatively stable proportions of this ingredient in the ashes of the grasses.

We may on the whole conclude that two alkalies, potash and soda; two alkaline earths, lime and magnesia; oxide of iron, silica, chlorine, sulphuric acid and phosphoric acid are essential to the development of plants.

#### § 4. *Occasional Ash-Ingredients.*

Other substances are occasionally found in the ashes of plants. Copper, lead, zinc, arsenic, fluorine and many other substances have been detected in plants. Nor is this to be wondered at, when we remember that the plant admits through its roots whatever crystalloid substances are dissolved in the soil waters. It is even found that such substances sometimes modify physiological processes in the plant; for special varieties of plants are occasionally found where unusual ingredients exist in the soil;



but, so far as is yet known, no substance not enumerated in the foregoing table is essential to the highest development of plants.

### § 5. *The Purpose of each Ash-Ingredient.*

Our knowledge of the functions of the several ash ingredients of plants is as yet very imperfect. It may be stated, however, that they are useful mechanically and chemically. Mechanically, some of them, like the silica in the straw of wheat, may serve to give strength and protection. Chemically, others may aid the plant in the production of its organic part. It would seem that certain earthy matters are specially related to certain kinds of non-nitrogenized matter—for example, that all plants which produce much starch, sugar, or gum, require much potash. With regard to the nitrogenized constituents of the plant, as gluten and albumen, it would seem that the presence of sulphates and phosphates is of especial importance to them. The former afford the sulphur which these nitrogenized substances contain, and phosphates are always plentiful in the ashes of those parts of plants which are rich in nitrogen, phosphoric acid appearing to facilitate the transfer of albuminoids from cell to cell. Chlorine performs the same office in relation to starch. Without iron chlorophyll is not formed, and without chlorophyll leaves are colorless, and refuse to decompose carbon dioxide. What, however, may be the peculiar physiological importance of soda, of lime, of magnesia, or of silica, it is impossible definitely to say.

The relation of each ash-ingredient to growth is modified by the nature of the plant itself. In some species of plants, and even in some varieties of the

same species, a much less proportion of earthy matter suffices to enable growth to go on than in others. Hence the well known fact that the growth of one kind of plant on a certain portion of soil does not prove its fitness for the growth of other kinds of plants. A fir tree may thrive on soil quite too poor in alkalies and other earthy matters for the healthy growth of a maple tree.

§ 6. *The Distribution of Ashes in the Plant, in different Parts and at different Stages of Growth.*

Two questions suggest themselves to the thoughtful mind. First. Does every part of each plant require the same proportionate amount of each ash-ingredient? A comparison of the composition of the ash of each grain with that of its straw gives at once a negative reply. In the wheat plant, silica is the leading ingredient of the ashes of the straw, while phosphoric acid predominates in the ashes of the grain. This might be inferred from what has been already stated respecting the special relations of one of these ash-ingredients to one of the most important classes of organic substances. Phosphoric acid is specially related to the nitrogenous substances which are so abundant in the grain, so scanty in the straw. There are about four times as much nitrogenous material in the grain as in the straw; and, correspondingly, almost four times as much phosphoric acid in the one as in the other. The varying composition of the different parts of the plant in relation to organic products necessitates a varying composition of their ashes.

The second question is this. Does a plant show a constant proportion and composition of its ash at all

stages of its growth? When we recollect that certain organic products are predominant in the earlier stages, others in the later stages of the growth and development of plants, we shall anticipate the answer to the above question. The absolute quantity of ash and the proportion of the ingredients of the ash differ in different stages of growth. Young leaves have little ashes; old leaves, a very large quantity.

### § 7. *Accidental Ash.*

So far it has been found impossible to determine with accuracy the amount of each ash ingredient essential to the full development of each part of the plant. But it is clearly shown that in very many, if not in most cases, there is an additional amount accidentally present, brought into the plant with the soil waters absorbed by the roots, and left behind when moisture is evaporated from the leaves, sometimes forming an incrustation or efflorescence on the surface of leaves and stems; sometimes deposited in crystals in the interior of cells or in the interstices between them; sometimes merely dissolved in and adding to the density of the sap, but not playing any important part in the nutrition of plants.

It is the presence of this accidental ash that confuses the results of many careful analyses. Where particular substances, especially if readily soluble in water, abound in a soil, plants are prone to show in their ashes a superabundance of these particular substances. The fact that beet-root shows 17 times as large a proportion of chlorine and eight times as much soda in some analyses as in others is to be accounted for, not by errors of analysis, nor by difference of variety of plant merely, but largely by the

soil in which the plants are grown being in some cases strongly impregnated with common salt, which has diffused itself by the rootlets into the root.

A part of the accidental ash is merely extraneous. The alumina, the manganese and much of the iron shown in certain analyses have been supposed to be externally adherent to plants. These substances have all a strong surface attraction for vegetable fibre, and are in consequence largely used in dyeing. Young plants, and the lower part of the stems of mature plants, are exposed to the splash of rains which bespatter them with the ferruginous clay forming a part of every arable soil. Such matter on drying adheres almost inseparably to the tissues of the plant, and must, of course, appear in the analysis of its ashes.

The attempt to determine how much of each ash-ingredient is essential to the perfecting of the plant is further confused by the tendency of elements belonging to the same chemical family to replace each other in compounds. It is suspected that to a certain extent potash and soda, lime and magnesia, iron and manganese, can be substituted for each other in the chemistry of life, as they certainly are in the constitution of many mineral species.

There is, therefore, wide variation in the amount and composition of the ashes of plants of the same species, as given by different skilful analysts; and the foregoing table is the mean of many somewhat widely divergent analyses. The extent of the variation for some of the substances contained in the foregoing table is given below :—

PLANT PRODUCTS.		K <sub>2</sub> O	Na <sub>2</sub> O	CaO	MgO	SiO	Fe <sub>2</sub> O <sub>3</sub>	Cl	SO <sub>3</sub>	PO <sub>5</sub>
Wheat Grain	from %.....	20	0	1	6	0	0	0	0	34
	to %.....	38	16	8	16	8	3	6	2	60
Wheat Straw	from %.....	1	0	3	0	61	1	0	1	2
	to %.....	17	8	9	5	74	10	9	6	9
Peas	from %.....	34	0	2	6	2	0	0	0	25
	to %.....	46	13	13	12	3	4	7	9	44
Pea Straw	from %.....	1	0	17	3	1	0	0	1	2
	to %.....	37	24	67	14	21	4	16	16	18
Carrot Roots	from %.....	17	10	7	1	1	0	2	3	8
	to %.....	51	35	17	9	5	2	6	12	15

### § 8. General Conclusions.

The great discrepancies of analysis shown above, which are as yet quite inexplicable, warn us to use such results with extreme caution in deducing rules for practical guidance. Yet there are certain general statements in relation to these inorganic constituents of plants, which lie at the very basis of scientific agriculture, and should be firmly fixed in the mind of the farmer.

1. Most of the substances found in the ashes of plants are not present accidentally, but are absolutely essential to the life and health of the plant.

2. Different plants and different parts of the same plant contain the materials of the ashes in different proportions.

3. The absolute quantity of ashes is different in

different plants, and in different parts of the same plant, and also in different stages of growth of the same part.

4. The substances contained in the ashes can be obtained by the plant only from the soil, or from the manure which the farmer places therein. They cannot be obtained in any degree, like the materials of the organic part, from the air. Further, in every crop the farmer necessarily removes a large quantity of these ash materials from the soil; and unless the latter contain these in unlimited quantity, it follows that cropping must exhaust the soil of the inorganic food of plants.

These truths in relation to the inorganic constituents of the plant, are among the most valuable results of modern chemistry in its application to agriculture.

## CHAPTER IX.

### THE ATMOSPHERIC FOOD OF PLANTS.

#### § 1. *The Plant Creates Nothing.*

In discussing vegetable life and growth it must be constantly remembered that the plant *creates* nothing. If a plant under any circumstances has become one pound heavier, then one pound of material has been gathered by the plant, either from the air in which its foliage is spread, or from the soil in which its roots are buried. Its growth is always an assimilation of pre-existent material. It is capable of decomposing certain compounds, and of rearranging their elements into new compounds; but beyond this it cannot go. It cannot add to the amount of matter in the world, and it cannot transmute one kind of elementary matter into another kind. The earth is not one grain the heavier, or the less heavy, by reason of all the plants that in the immeasurable ages past have grown on the land or in the sea. Nor is there in the world, by reason of vegetable life, one atom more or less of oxygen, of hydrogen, of nitrogen, of carbon, or of any other elementary substance than when this planet was first formed.

#### § 2. *The Composition of Air.*

Whence then do plants derive their material? Speaking of land plants, from the air and from the soil. What part of their material do they derive from the air and what from the soil? Speaking generally,



they derive their organic part from the air, their inorganic from the soil; but for a complete reply to this question it will be needful to enquire particularly into the supplies of plant food furnished by the air and by the soil. We shall in this chapter consider the air as a magazine of food supply for plants, reserving to the next chapter a discussion of the soil in relation to the sustenance of plants.

As has been already stated, atmospheric air consists of a mixture of two gases, oxygen and nitrogen, into which is diffused variable quantities of vapour of water, carbon dioxide, ammonia, other exhalations of vegetable and animal life, and products of combustion and decay. Where animals are crowded together, oxygen is somewhat deficient, and carbon dioxide, ammonia and organic emanations are in excess; while the air is somewhat richer in oxygen where vegetation is growing freely. But, on the whole, animal life and vegetable life are so balanced in the world, and the atmosphere is so thoroughly stirred up and commingled by winds, that in the open country atmospheric air preserves, except in relation to moisture, to carbon dioxide, and to ammonia, a very constant composition. If for the moment we omit these more variable components, the air may be said to consist of 79 cubic feet of nitrogen and 21 cubic feet of oxygen in every 100 cubic feet of air; or, which is approximately the same thing, of 77 pounds of nitrogen and 23 pounds of oxygen in every 100 pounds of air. The amount of carbon dioxide present in air is somewhat variable. The extreme range of 500 analyses made a few years ago, was from 47 to 87 hundred-thousandths of the weight of air, the average being about 6 ten-thousandths. By volume this is about 4 ten-thousandths

Ammonia being very soluble in water is almost completely washed out of the air by rain; it accumulates in the air during dry weather. The quantity fluctuates greatly, but is always small. On the average its weight in the air is nearly one part in one million. Vapour of water may be less than  $\frac{1}{4}$  per cent. or more than 3 per cent. of the weight of the air. As a rough approximation to the truth we may put its average amount at one per cent. of the weight of the air.

### § 3. *Air as Food for Plants.*

The air then surrounds the foliage of plants with abundant uncombined oxygen and nitrogen, with a smaller amount of carbon dioxide and water and with very minute proportions of other substances, and we have seen page 118, that leaves are adapted to absorb and to appropriate to the needs of plants gaseous materials.

Are all the constituents of the air available as food for plants? The answer to this must be that by far the greater part of the air is not adapted to nourish plants. It is one important function of plants to supply oxygen to air; therefore they do not on the whole absorb oxygen. It is true that under exceptional circumstances some parts of plants absorb oxygen from the air. Germinating seeds, expanding buds, and opening flowers do this; but the net result of the growth of plants is to return to the air at least ten times as much oxygen as they absorb from it. Nitrogen is necessary to the growth of plants, but it appears to be physiologically impossible for agricultural plants to feed directly on the uncombined nitrogen around them. A very little they derive by their leaves from the nitrogenous compounds that exist in very small amount in the air; but by far the

greater part of their supply of nitrogen is absorbed by the roots. Neither the oxygen nor the nitrogen of the air is plant food. The carbon dioxide in the air, however, is absorbed and decomposed by the foliage of plants, and is the source from which by far the greater part of the carbon of plants is derived, and is, therefore, a most important plant food. The water held in solution by the air does not directly minister through the leaves of farm crops to their nourishment, although as the source of dews, rains and snows it supplies through their roots one of the essentials of their life and growth.

*Examples.*

137. Assuming the composition by weight of the air, on some summer day when the barometric pressure is 29.8 inches, to be  $N\ 75.9\%$ ,  $O\ 22.98\%$ ,  $H_2O\ 1.06\%$ ,  $CO_2\ .0599\%$  and  $NH_3\ .0001\%$ ; what weight each, (a) of free nitrogen, (b) of free oxygen, (c) of water, (d) of carbon dioxide, (e) of carbon, (f) of ammonia and (g) of hydrogen rests on one acre of land? Give the answers in tons except in the case of ammonia, where the answer may be given in pounds.

138. If in the circumstances given above,  $\frac{1}{4}$  of the moisture in the air were to be deposited as rain, what would be the depth of the rain fall in inches?

139. If a plant exposes to a wind moving ten miles an hour one square foot of surface, when the barometric pressure is 30 inches and the temperature is  $60^\circ$ ; how much carbon dioxide comes into contact with the plant in ten hours, the proportion of carbon dioxide being  $\frac{6}{10,000}$  of the weight of the air?

140. If a crop of wheat has assimilated in grain and straw 2,100 lbs. of carbon, 260 lbs. of hydrogen

and 56 lbs. of nitrogen, and if all the carbon has been derived from carbon dioxide, all the nitrogen and a part of the hydrogen from ammonia and the rest of the hydrogen from water ; how much carbon dioxide, ammonia and water must have been decomposed by the wheat plants ? How many tons of air containing  $6/10,000$  of carbon dioxide would be needed to supply the carbon of such a crop as is supposed in the preceding question ?

141. If one acre of oats assimilates 2,500 lbs. of carbon, what per cent. of the amount of carbon over an acre of land is that, when the pressure of the air is  $14\frac{3}{4}$  lbs. on the square inch and the proportion of carbon dioxide is 549 millionths of the weight of the air ?

142. If the proportion of ammonia present in the air is one millionth and the pressure of the atmosphere is  $14\frac{3}{4}$  lbs. on a square inch ; what weight of ammonia rests above one acre of ground ?

143. How much ammonia would be required to furnish a crop with 100 lbs. of nitrogen ?

## CHAPTER X.

### THE SOIL.

#### § 1. *Nature and Origin of the Soil.*

The soil is derived from the waste of the rocks of the earth's crust ; but it is not a mere mass of rubbish ; on the contrary, it is a complex mixture of a number of substances in which many interesting chemical changes are constantly going on, and which possesses many important properties in reference to the nutrition of the plants that grow on it.

With regard to the origin of soils from rocks, we may take as an example the common and durable rock granite. In a piece of granite we can usually perceive three distinct minerals : 1st, quartz or flint, which is nearly pure silica ; 2nd, feldspar, with flat and shining surfaces of a white or reddish colour, and usually the largest ingredient in the mass. It is a compound of silica with alumina and potash, or soda, or both ; 3rd, mica, black or silvery scales with metallic lustre, and composed of silica, alumina, oxide of iron, oxide of manganese, potash, and sometimes magnesia. \*

Now a mass of such granite is slowly acted on by the weather ; that is, by the rain-water charged with carbonic acid. The latter substance gradually decomposes the feldspar, removing its potash and soda, and

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\* If the teacher can obtain a piece of granite, these minerals may be easily shown to the pupils. The allied rock syenite has the mineral hornblende instead of mica. Hornblende is usually of a blackish colour, and consists principally of silica, magnesia, lime, and oxide of iron.

leaving the silica and alumina, which then become soft and crumbling, and ultimately fall into fine clay. The feldspar being thus broken up, the quartz and mica fall asunder into sand and flat scales, and a soil results, which in its texture will be partly of a sandy and partly of a clayey nature, and as to composition will contain silica, alumina, soda, potash, oxide of iron, and perhaps carbonate of lime, phosphate of lime, and other substances contained in the minerals which may be mixed with the granite. These substances will be in the state of clay, which has the power of retaining the more soluble matters in its pores, or in the state of grains of sand, which may be themselves gradually undergoing waste, and yielding their ingredients to the soil.

Let now a mass of such soil be acted on by water, and the clay may be washed away in whole or in part, and deposited in valleys and flats, giving rise to a stiff soil. The sand may remain or be washed into some other place, and will constitute a sandy or light soil, and there may of course be any number of mixtures of these two opposite kinds.

Further, let plants grow on this soil, and their roots and fallen leaves decay in and upon it, and a certain quantity of vegetable mould will be produced, and mixed with the soil, constituting its organic part.

It will be observed that these statements refer to a granitic soil only, but in the case of other rocks the process is similar; though it is evident that the greater the variety of the rocks and minerals ground up to form the soil, the more complex will be its composition. Still as the common rocks are everywhere composed of a few elements, it follows that in the main the soils of all parts of the world are alike, differing principally

in the *proportions* of the not very numerous substances of which they are composed.

Such being the origin of the soil, it is evident that, regarding it from different points of view, we may for practical purposes form different classifications or arrangements of soils. Let us next consider these.

## § 2. *Classification of Soils according to Mechanical Texture.*

We may regard soils as more or less coarse or fine, and thus obtain a classification depending on the mechanical texture of the soil, which, for practical purposes, is much used and of great value. In this respect the soil may vary from coarse pebbles or loose sand to the finest and most tenacious clay; and in general, those soils are best adapted for agriculture which consist of mixtures of sand with a moderate quantity of clay and a little vegetable matter. When sand or other coarse matter predominates, the soil is deficient in the power of retaining water and the soluble and volatile parts of manure. When clay is in excess, the soil is too retentive of water, is not easily warmed, does not admit of access of air, and consequently does not allow those chemical changes to take place in the soil and manures placed in it, which are necessary to prepare proper food for plants. The following classification of soils in reference to these points has been proposed.

1. *Pure Clay*; from this no sand can be extracted by washing.
2. *Strong Clay*, or brick clay, contains less than 20 per cent. sand.
3. *Clay Loam* has from 20 to 40 per cent. sand.



4. *Loam* has from 40 to 60 per cent. sand.
5. *Sandy Loam* has from 60 to 80 per cent. sand.
6. *Sand* has less than 20 per cent. clay.

*Examples.*

N.B.—In answering these questions deduct the organic matter, and determine the percentage of sand in the remainder.

144. A certain soil free from organic matter contains 45% of its weight of sand. What should it be called?

145. A similar soil has 35% clay. What name designates it?

146. A soil consists of 12% organic matter, 37% sand, and the rest clay. What is its proper name?

147. What is the name of a soil of which 15% is organic matter and 65% is sand?

148. What is the proper term to designate a soil of which 20% is organic matter and 70% is clay.

§ 3. *Classification of Soils according to their General Chemical Characters.*

We may classify soils according to their predominant or leading ingredients. Here we may divide soils into organic and inorganic parts, the former consisting of the remains of plants and animals mixed with the soil, the latter of the mineral substances originally present in it. These last again may consist of silica, alumina, or lime in predominant quantity. Hence we obtain such a classification as the following:—

- X 1. *Organic soils*, or those of bogs, and the vegetable mould of the woods, consisting in great part of partially decomposed vegetable matter.

2. *Silicious soils*, or those in which silicious sand is the prevailing ingredient, and which are often formed from the waste of sandstone rocks.

3. *Argillaceous soils*, or those which consist principally of clay, and are often formed from the waste of slates and shales.

4. *Calcareous soils*, or those in which lime is a principal ingredient, and which may be produced from the waste of limestone, chalk, or marl.

#### § 4. *Classification of Soils according to Details of Composition and Relative Fertility.*

We may classify soils of any or all the kinds separated in the above heads, according to their fertility or barrenness in relation to our cultivated crops, that is according to the presence or absence of the materials of the ashes of those crops. No soil, unless it contains some substance poisonous to plants, or is a mere shifting silicious sand, is absolutely barren; but we call a soil barren which will not produce such plants as the farmer cultivates. Such a soil may be made fertile by adding to it the substances in which it is deficient; but if this cannot be done except at a cost as great as or greater than that for which fertile soil can be procured, the soil may be regarded as practically barren and worthless.

The mechanical texture and predominant ingredients of soils, though important to their fertility, do not absolutely determine it. A sandy, loamy or clay soil, or a silicious or calcareous soil may or may not contain all the materials of the ashes of our crops; and if it does not it will be barren. This obliges us to consider the composition of soils in detail. Bearing

in mind then the three classifications of soils above explained, let us next proceed to consider their composition.

This will be seen at a glance in the following table, from Johnston, representing the ingredients of three different soils, with their relative properties:—

*Composition of Soils of Different Degrees of Fertility.*

	Fertile without Manure.	Fertile with Manure.	Barren.
Organic matter.....	97	50	40
Silica (in the sand and clay).....	648	833	778
Alumina (in the clay).....	57	51	91
Lime .....	59	18	4
Magnesia .....	8½	8	1
Oxide of iron.....	61	30	81
Oxide of manganese.....	1	3	½
Potash .....	2	trace	trace
Soda, } chiefly as common salt	{ 4		
Chlorine, }	{ 2		
Sulphuric acid.....	2	½	
Phosphoric acid.....	4½	1½	
Carbonic acid (combined with the lime and magnesia) .....	40	4½	
Loss .....	14	.....	4½
	1000	1000	1000

## CHAPTER XI.

### THE RELATION OF THE SOIL TO PLANTS.

#### § 1. *The Soil as an Anchorage for Plants.*

The soil affords the plant mechanical support. By its roots the plant is anchored to the ground and upheld against wind and rain. To subserve this purpose the soil must have weight and coherence.

Dry Organic	soils weigh about 50 lbs. per cu. ft.
" Heavy Clay	" " " 75 " " "
" Silicious or Calcareous	" " " 110 " " "

From these numbers it is possible to calculate the weight per cubic foot or per acre, to a depth determined, of soils in general, which are mixtures in varying proportions of the substances given above.

#### *Examples.*

149. A calcareous sandy loam consists of 45% of its bulk silicious sand, 10% calcareous sand, 35% clay and 10% organic matter. What does it weigh per cubic foot, and what is the weight of an acre of such soil one foot deep?

150. Of the bulk of a certain clay loam 60% is clay, 25% sand and 15% organic matter. What is the weight per cubic foot and per acre 1 foot deep?

151. The roots of a maple interpenetrate a mass of loam, half silicious sand and half clay, measuring 30 feet long, 25 feet wide and 4 feet deep. What weight of soil anchors the tree?

The weight of an acre of soil one foot deep may be

estimated at from  $3\frac{1}{2}$  million to 4 million lbs., that is from 1,750 to 2,000 tons. In the calculations that follow, the last number will be employed.

152. Calculate the weight in tons of the several ingredients that make up an acre one foot deep of the soil fertile without manure, whose analysis is given on page 161.

153. If a cart-load of lime weighs 1,600 lbs., how many loads of lime would be needed to give to the soil fertile with manure as much lime to the acre one foot deep, as is contained in the land fertile without manure?

154. If it cost 5c per lb. to supply phosphoric acid to the soil in some form, what will it cost to bring up one acre one foot deep of the soil fertile with manure to the richness in phosphoric acid of the soil fertile without manure?

155. Manufacturers of artificial manure reckon potash worth 6 cents a lb. in manure; at that rate what would it cost to bring one acre one foot deep of soil No. 2 to the richness of potash of soil No. 1, if a trace of potash mean  $\frac{1}{100}$  of 1%.

The cohesion of a soil, in other words its stiffness, may be either too great or too small. The so-called heavy clays, (which are, however, heavy, not because of the weight of the soil, but because of the cohesion of its particles), and especially clays which contain large quantities of alkali, when wet form a tenacious, plastic, intractable mass; and when dry cohere into stony lumps, through which the plough can scarcely force its way, and which will not crumble down into a state of fine tilth. In such soils seeds do not readily germinate, and into them roots

do not easily penetrate. On the other hand light sands, easily displaced by the wind, do not afford a foot-hold for plants because of their lack of coherence. When the thin vegetation that in the lapse of ages has slowly crept over such surfaces of shifting sand, and that by its rootlets binds the particles together, is once broken up, it becomes a difficult task to re-establish vegetation.

## § 2. *The Soil as Supplying Moisture to Plants.*

The soil is a reservoir from which the plants cultivated on the farm derive almost all their supply of that indispensable nutriment, water. Water exists in the soil and subsoil in three forms—ground water, capillary water, hygroscopic water. Ground water is that which will drip from the soil; capillary water is that which, like the oil in a lamp wick, creeps up through the pores of the soil from the ground water, and hygroscopic water is that which a dry soil can absorb from moisture-laden air.

If we dig down a few inches in some cases, a few feet in others, we reach a stratum of soil so surcharged with water that the moisture oozes out more or less rapidly and collects as a pool at the bottom of the excavation—a well is formed. The level at which this ground-water stands in wells is uniform over considerable areas of flat sands and gravels, and is called the water-table. When the subsoil at or below the water-table is permeable, the water-table rises with abundant rains, and falls in long-continued droughts, so that wells are filled to overflowing or run dry together over considerable areas. In deep tenacious clays, however, the wells are usually filled not by infiltration from below

but by overflow from above. They are then of the nature of mere tanks, each independent of its neighbours. Below the water-table the pores of the soil are filled with water, air cannot penetrate, and the roots of agricultural plants will not grow.

Water is attracted by and creeps slowly in all directions over many surfaces in contact with it. Thus a clod of dry earth of which one corner is dipped in water, will soon become damp throughout. Water so distributed through the pores of the earth is called capillary water.

From the capillary water in the soil land plants derive their chief supply, although many plants send down a few strong roots into the ground water. The height to which capillary water rises above the water table, varies with the nature of the soil and with the state of tilth. In fertile, well worked soil, it may be as much as six or eight feet, so that to that height moisture will be supplied in a slow ascending current sufficient to keep the soil damp and dark in colour, replacing the water lost by evaporation from the leaves of plants and from the surface of the soil. It must not be supposed that capillarity gives rise only to ascending currents of moisture in the soil. The texture of all cultivated soils is too close to permit water poured on the surface abundantly to sink down out of sight immediately, as if it were poured on a pile of broken stone. It forms puddles on the surface or runs down over it in streams. But the capillary action of the soil begins at once to convey the supernatant water downward. The water soaks into the land. From particle to particle the moisture slowly descends, until it has more or less completely



disappeared from the surface. After rain, capillary currents creep downward, adding to the ground water. In drought, capillary currents creep upward, supplying surface evaporation. Lateral capillary currents distribute moisture right and left from damp to dry adjacent ground. Thus a continual slow circulation of capillary moisture refreshes the rootlets of growing plants. The same surface attraction which distributes capillary water also retains it in the pores of the soil. Soils differ greatly in their capillary power as measured by their retentiveness. If dry soils be thoroughly wetted and permitted to drain, they will retain varying amounts of water. Thus coarse quartz sand will retain 25% of its weight of water, marl 30%, loam 50%, pure clay 70%, garden mould 90%.

Hygroscopic water is that which a dry soil is able to absorb from damp air. The amount varies much with the chemical constitution of the soil, with the temperature and with the degree of saturation of the air. If the soils of which the power of retention is stated above were thoroughly dried and exposed for 24 hours to saturated air, it would be found that the quartz sand would gain nothing in weight by absorption, marl 30%, loam 35%, pure clay 50%, garden mould 55%. Generally speaking hygroscopic power increases with capillary power. Experiment has shown that hygroscopic water in some soils can supply sufficient moisture to keep some kinds of plants from wilting.

### § 3. *The Soil as a Store-House of Nitrogen.*

The soil supplies almost all the nitrogen that plants require. In ammonia, in nitric acid, and in

comparatively inert nitrogenous compounds of organic origin, all fertile soils contain much nitrogen. That the plant depends chiefly upon the soil for its nitrogen is evident. Nitrogen abounds in the air; but we have seen that the plant cannot assimilate atmospheric nitrogen. Ammonia exists in air, and some doubtful experiments seem to indicate that the leaves of plants can absorb and use it; but so small is the average amount of ammonia in the air that, relatively to the demands of the growing plant, carbon dioxide is nearly 400 times as abundant as ammonia. To make the same statement concretely, it would require more than a year for a plant to collect from the ammonia of the air the nitrogen required to organize with the carbon which the plant collects from the air in a day. Nitric acid also is found in the air, but in still smaller quantity, so that if a plant had to collect its nitrogen from nitric acid as diffused in the air, ten years would scarcely suffice for gathering enough nitrogen for the daily growth of a plant. If atmospheric nitrogen is not available for the plant, and if the atmospheric supply of nitric acid and ammonia together, for 350 years, would not furnish the nitrogen required for one year's growth of plants, it is evident that vegetation cannot be fed with nitrogen from the air; it must draw its nitrogen from the soil.

The soil is a store house of nitrogenous food for plants. This is evident for three reasons. 1st. Because to it the rains bring down the ammonia and nitric acid which escape into the air through decay or combustion of organic substances, or which are formed in it by the electrical disturbances or by the chemical reactions of which the atmosphere is the theatre. 2nd. Because to it is restored in large part the

nitrogenous compounds which are the debris of life, whether the excreta of animals, the falling foliage of plants or the dead and decomposing bodies of animals and plants. 3rd. Because in ways but imperfectly understood the soil is the seat of an active manufacture of nitrogenous compounds from the nitrogen of the air by bacterial life, more particularly by bacteria that are parasitic on the roots of leguminous plants.

1st. The chief reason for the smallness of the amount of ammonia and nitric acid in the air is that, being both exceedingly soluble in water, they are washed out of the air by every shower, and so, almost as fast as they appear in air, they are transferred by rain to the soil. During dry weather ammonia and nitric acid accumulate in very small quantity in the air. When wet weather sets in, the first showers bring down almost all the accumulation, and later showers find little or none. Hence the proportion of these substances varies greatly in different rains.

Ammonia varies from no appreciable quantity up to almost one part in 50,000 of rainwater, and nitric acid from nothing to one part in 100,000 of rainwater. Although the amount of each of these substances brought down to the earth by the rain of a year fluctuates within narrower limits than the amount brought down by individual showers, yet it is not possible to speak very positively even in this regard. As a first approximation to the truth it may be said with reserve that in our climate about 12 lbs. of ammonia and 5 lbs. of nitric acid are annually deposited by the rain-fall on an acre of land; that is between 11 and 12 lbs of nitrogen in these two compounds. This amount, though not

unimportant to the growth of plants, is quite inadequate to the requirement of crops, which, if good, assimilate from 50 to 100 lbs. of nitrogen per acre.

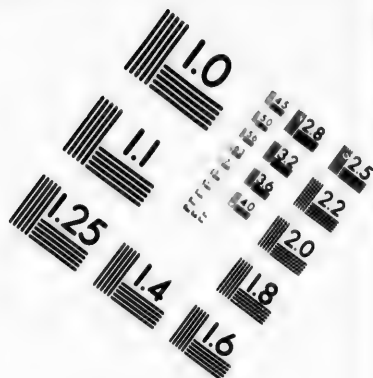
2nd. In the economy of the world but little of the nitrogenous material prepared by plants finally escapes consumption by animals, so as to go to waste by decay. Herbage, fruits, seeds, are consumed by various tribes of beasts and birds. Even fallen leaves, boughs torn off by winds and tree trunks overthrown in the forest afford food to innumerable hosts of invertebrate forms which, individually insignificant, in the aggregate modify profoundly the course of nature. But animals in the act of living reduce the food which plants have prepared for them, and which they have consumed, to compounds which either are inorganic or closely approach to the inorganic condition. The carbon of their food is almost wholly combined with oxygen and returned as carbon dioxide to the inorganic world in the act of respiration. The nitrogen of their food is organized into nerve and muscle. These waste in the act of living, and their nitrogen is nearly all returned to the soil by secretions in the form chiefly of urea, hippuric acid or uric acid. Urea characterizes the urine of mammals whose food is highly nitrogenous; hippuric acid abounds in that of herbivorous mammals, while uric acid is characteristic of the excretions of birds, reptiles and invertebrates. But, whether in one form or another, the nitrogenous waste of life is returned to the soil.

3rd. The attention of scientific observers begins to be attracted to the effects produced by microscopic forms of life which flourish in the organic matter of soils. Modern research has shown how, in many

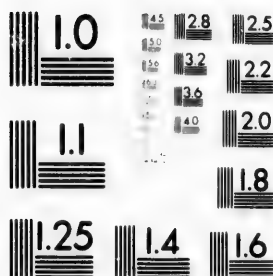
ways, the greater life which our eyes see is ministered to, modified by or destroyed by swarming forms of life that abound in the air, in the waters, in dust, in the soil, everywhere; so minute that the known forms almost elude the higher powers of our best microscopes, and suggest irresistibly the belief that below them exist unknown forms that quite escape our vision, but that by their numbers and by their rapid multiplication work out unique but most important results in the world of life. Dwelling in the borderland between the vegetable and animal kingdoms they have been sometimes assigned to the one, sometimes to the other kingdom, but, as in function they are allied to the fungi, they are now almost universally classed with vegetables. Sometimes, with reference to their many kinds, their vast numbers and their small size, they are collectively called microdemes, literally little populations. Sometimes, they are called microbes, literally small living things, a term that has of late become familiar through its special application to forms that multiplying in living animals cause many widespread epidemic diseases, as the influenza microbe, the cholera microbe, etc. Some of those earliest discovered were rod-like in form, hence the name bacteria plural of bacterium, a latinized form of the Greek bacterion, a staff. But other forms than staff-like abound; some more or less spherical, some slender threads, straight, spiral, contorted or convoluted. All are destitute of chlorophyll; they cannot therefore gather nourishment from inorganic matter by the aid of sunlight. Hence they consume organic food as found in the fluids of living plants or animals, in their dead and decaying bodies, or in their dejecta. They are

creatures of fermentation, putrefaction, disease, death and darkness. Vigorous life and sunlight are unfriendly to them. The products of their life, their secretions, are important and unique. Just as the yeast plant, living in a solution of sugar, produces carbon dioxide and alcohol, so bacterium lactis, living in milk, produces carbon dioxide and lactic acid. In the case of many microbes of disease it is suspected that their poisonous secretions work more mischief than their mere consumption of the material of living tissues.

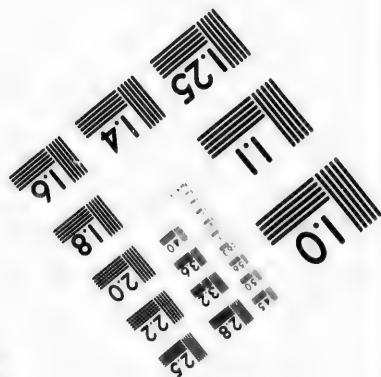
Many such forms prosper in rich soils. Many kinds of fermentation occur in them. Two must be briefly alluded to. One, or perhaps more than one, species of microbe lives and multiplies in soils containing nitrogenous matter, and produces nitrates. Its life is most active in darkness, at a temperature of about 100° F., at depths to which the oxygen of the air can penetrate, in soils that contain carbonaceous matters, nitrogenous matters, phosphates, alkalies and a due proportion of moisture. Light is unfriendly to these microbes; the absence of oxygen is fatal; temperatures below 40° F. arrest their activity; temperatures above 130° F., complete desiccation, and various vegetable and mineral poisons destroy them. Where they flourish, salts of ammonia, decaying animal matters and inert nitrogenous substances are rapidly oxidized into nitric acid, which unites with such alkalies or alkaline earths as may be present, and which in combination with them forms the most valuable because the most readily available source of nitrogen to higher plants. Another microbe plays a part still more important in the nitrogenous nutrition of the higher plants. It has long been



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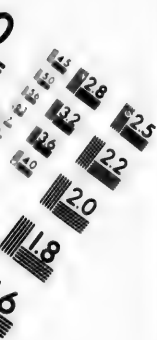
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suspected that the leguminous plants such as clover, vetches, peas and beans, add to rather than subtract from the nitrogenous wealth of the soil, or at least that they do not deduct from the nitrogen accumulated in the soil as much as they organize in their own structure. From recent researches it seems highly probable that some forms of microbic life, parasitic on the roots of leguminous plants, have the power of assimilating nitrogen from the air, especially when growing in soils rich in carbonaceous matter, thus increasing the nitrogenous wealth of the soil.

Whether washed from the air, or collected from the debris of animal and vegetable life or manufactured by bacterial ferments in the soil, certain it is that large amounts of nitrogen in various forms of combination are stored up in the organic matter of the soil. In the form of ammonia an average soil may contain about 20 lbs of nitrogen to the acre; a rich garden soil may contain as much as 75 lbs. In the form of nitric acid the amount of nitrogen will vary greatly with the weather, as the nitrates are leached out of the soil by rains, and accumulate in dry weather. There may be in a good soil as little as 20 lbs of nitrogen in the nitrates contained in an acre of soil one foot deep, or as much as 500 lbs. The inert nitrogen of a fertile soil, associated with its organic matter, vastly exceeds the amount present in ammonia and nitric acid. It may amount to from 2% to 5% of the organic matter of the soil. The average of fertile soils will give about 16% of the total weight of the surface soil, or from 4,000 to 8,000 lbs. of nitrogen per acre one foot deep.

#### § 4. *The Soil as a Storehouse of Inorganic Food for Plants.*

The soil is also the storehouse from which plants derive all their inorganic nutriment. The potash, soda, lime, magnesia, iron, silica, phosphoric acid, sulphuric acid and chlorine necessary to the development of plants must be present in the soil or plants cannot grow upon it. The percentage of any of these ingredients may be but small, because a small percentage of the composition of an acre of soil one foot deep, weighing 2,000 tons, 4,000,000 lbs, represents a large absolute amount, one one hundredth of one per cent. being 400 lbs; but each ingredient must be present. In fertile soils the constituents of the ashes of plants are present in very different proportions from those in which they occur in the plant; some of those most abundant in the plant being the rarest in the soil, and *vice versa*. Hence the mass of the soil is to be regarded not as in itself food for plants, but only as holding and containing this food, and giving support and protection to the plant and its roots. The substance alumina, which we find in the soil and not in the plant, is especially important in these ways. It is possible to reduce a fertile soil to barrenness without materially altering its weight, bulk, or mechanical texture.

The fertility or barrenness of soils does not altogether depend on the quantity of organic matter, that is of vegetable mould or humus present in the soil. This is no doubt of great value. It is constantly yielding by its decay, carbonic acid and nitrates to nourish the organic part of the plant. It is setting free, little by little, the earthy matters of its own

ashes. It is also by its decay inducing chemical changes, which tend to set free other matters held in combination in the particles of the soil. It renders clay soils more friable, and sandy soils more retentive of volatile substances, and of substances in solution. It darkens the color of the soil, and thus enables the solar heat to have more effect on it. These are all important uses. Still there are some alluvial soils nearly destitute of organic matter, and yet of almost inexhaustible fertility, and there are some peaty soils very rich in organic matter, yet very barren. If organic matter has accumulated in a soil by the growth of vegetation of a high order, then, conditions of heat and moisture being favourable, the soil will be fertile, and if the organic matter be abundant, they will be exceedingly fertile. Such soils were formed by the growth of the deciduous forests of Canada, and by the growth of the grasses of the western prairies. But if the organic matter has resulted from the growth of lower forms of vegetation, as of the conifers on our gravel ridges or of mosses in bogs, the soil may be comparatively barren. Important though the organic matter of the soil is, the mineral matter is more so.

Not only must all the inorganic matters needed by the plant be present in the soil, but they must be present in an available form. Inorganic matter enters the plant only through the tender tissues of the rootlets, in a state of solution. Unless then these matters are in such a state as to be soluble in soil-water, that is in water which holds in solution carbonic acid or alkalies or other substances derived from the soil or the air or the roots of growing plants, their presence in the insoluble state is of no immediate value to the plant.

It is true that they need not be very soluble. Phosphoric acid in solution in soil water does not in any case exceed one part in 50,000 ; but as the formation of every pound of dry vegetable matter is attended by the evaporation of at least 250 pounds of water, this very small proportion of phosphoric acid in solution would account for 5 per cent. of this substance in the vegetable structure. It is true also that the whole amount needed is not necessarily available at once. If while a crop is growing the chemical changes which are incessant in a soil, progressively render soluble the needed nutriment as it is required, the crop will flourish ; even if at no given moment of the season the soil holds ready all the nutriment requisite.

Chemical analysis of soils is of comparatively little service as a guide to agricultural practice, just because it fails to answer the question how much of the nutrient material in the soil is available or will readily become available for the wants of a crop. It can accurately state the amount of each ash ingredient present in the soil. It can demonstrate the absolute barrenness of a soil by proving that it is destitute of some essential ingredient of the ashes of plants. It can show what amount of each ash ingredient can be leached out of the soil by water. But plants can undoubtedly take from a soil more than pure water will dissolve from it, just how much chemistry cannot say ; and it cannot tell the farmer what additional amount will be set free during the growth of the crop by the chemical changes resulting from the development of roots in the soil, from the operation of bacterial life, from the influence of heat, moisture and frost, and from the combined interactions of the many

substances contained in the soil or supplied to it as manure.

Soils differ materially in their power of retaining soluble substances.

The absorbent and retaining power of soil is one of its most remarkable properties. The arable soil is not a mere sieve through which any matter in solution can pass freely; but, on the contrary, it has a great power of retaining, as in a filter, all saline and other substances that may be present in the water permeating it. This power is very different in different soils, and in the same soil in the case of different substances. In passing through any ordinary soil the dark water of a dunghill, or a saline solution, will lose large portions of its contents, which remain, so to speak, entangled among the particles of the soil, or adhering to their surfaces. In light and sandy soils this power of retaining nutritive substances is less; in heavier soils, greater; in soils having much vegetable matter it is strongly marked; and in light soils of a red or brown color, having the particles mixed with oxide of iron, it is greater than in colorless, sandy soils. Extremely light sands, and extremely compact clays, possess this power in the smallest degree, so that the porosity of the soil seems to be mainly important in reference to this property.

Further, the absorptive property of the soil appears to be connected with a chemical action upon the substances present in it; some solutions being decomposed in passing through certain soils, and one substance retained while another is allowed to pass. Thus salts of potash and ammonia sometimes part with these bases to the soil; the acids present entering into other combinations.

It would seem from various experiments that the matters thus absorbed by the soil are more readily available to plants than those in chemical combination with its ingredients. The latter are only little by little set free by decomposition; and this is believed to explain the effect of tillage in improving soils, and also the fact that chemical analysis often shows a larger amount of nutritive substances than experiment proves to be practically available. Thus, if an analysis shows a large quantity of phosphate of lime in a soil, it may yet happen that plants like wheat, which require much of this substance, may not be able to obtain it in time, in consequence of its occurrence in the form of solid particles or sand. Tillage, by stirring the soil and promoting the solution of these particles and their mechanical absorption by the ground, may make them available; and may consequently appear to enrich the soil. The presence of organic matter in the soil has a double influence in these processes. First, by producing carbonic acid, it adds to the solvent power of the water of the soil. Secondly, by its mechanical absorbing power, it retains the substances dissolved till required by the roots of the crop.

Certain chemical manures also, as common salt and lime, are highly important in the solution of inert substances; and the matters thus dissolved, being absorbed by the soil, are retained for use.

This property of soils is of immense importance in the formation of composts, and the use of bog earth under manure heaps and stables. The earth and bog become mechanically saturated with nutritive matters, and thus become most valuable fertilizers.

The absorbent power of soils also serves to illustrate



the advantages of subsoil ploughing and draining, as it is of the highest importance to bring all parts of the soil within reach of the air and water permeating it, and that it may absorb nutritive matters instead of rejecting them from its surface. Were it not for this property, soluble substances present in the soil would be immediately washed out of it, and fallowing, tillage and draining would rapidly impoverish the land by allowing its soluble constituents to be carried off by water.

#### § 5. *The Soil in Relation to Heat.*

The temperature of a given soil depends on the amount of heat it receives from the sun and gains or loses by the winds that blow over it, by the rains that soak into it, or by the soil water that percolates through it. The temperature of the winds and the rains and the amount of sunlight are nearly uniform over broad belts of country and determine its general climate. But in broken country the climates on opposite sides of a hill may widely differ. One farm perhaps slopes gently to the southeast, lies open to morning suns, and is sheltered from bleak northwest winds. Another farm has a northern exposure, and is swept by all the bitterest storms of late fall, winter and early spring. The first farm enjoys a climate more genial than that of the other by the equivalent of several degrees of latitude.

Under the same circumstances of climate and exposure it is well known that soils differ greatly in temperature, because they differ in their relations to heat. Some soils have a greater specific heat than others, they require more heat to warm them, and they yield up more heat in cooling than other soils.

The surfaces of some soils absorb from sunlight more heat, and radiate more in darkness than others do. Finally some soils conduct heat downward from the surface into the interior more rapidly than others do.

*Specific heat of soils.* Taking the specific heat of water as 1 that of dry peaty matter is .21, of dry clay .14, of dry silicious sand .1, and of dry chalk .18. From these numbers may be calculated the specific heat of dry soils that consist of various admixtures of organic matter, clay, sand and lime.

*Examples.*

156. What is the specific heat of a dry clay loam consisting of 25% sand, 10% organic matter and 65% clay?

157. What is the specific heat of a dry calcareous loam consisting of equal parts of chalk, sand, clay and humus?

But wet soils differ very little in specific heat, because water has in comparison with the dry matter of soils so high a specific heat.

158. What are the specific heats of wet humus, clay, sand and chalk each containing 50% of its weight of water?

159. What would they be if in each case the weights of water and of soil were equal?

160. What is the specific heat of a soil consisting of 25% water, 25% humus and 50% silicious sand?

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*Absorbent and radiating power of soil.*—The power of the surface of a soil to absorb the radiant heat of the sun depends largely on its colour. Dark coloured surfaces absorb heat most readily. All soils sprinkled over with a thin coating of lamp-black and

exposed to the full blaze of sunlight speedily acquire a comparatively high temperature, and nearly all the same temperature. If whitened with a sprinkling of magnesia, they soon acquire in the same circumstances equal temperatures, but many degrees lower than when blackened. Similarly, dark coloured soils rise in temperature under the same exposure to sunlight several degrees above soils naturally light-coloured.

The surfaces which absorb heat most readily also radiate it away most readily, so that they cool most rapidly by night as well as heat up most rapidly by day.

*Conducting power of soils.*—It is evident that the difference of temperature between the upper and lower layers of a soil warming in the sun will be less as the conducting power of the soil is greater. The conducting power of soils is, however, small in any case. It is greater in compact and in stony or gravelly soils than in loose, friable, well-tilled soils. Frost penetrates more deeply into the soils that have the higher conducting power. Hence in our climate, under roads and streets the ground is frozen four or five feet deep, while at the same time in gardens with a light surface soil, protected by snow, the frost descends but a few inches.

## CHAPTER XII.

### EXHAUSTION OF THE SOIL.

The table of the composition of soils, when compared with that of the ashes of cultivated plants, throws light on the causes of *exhaustion of soils*, and on the advantages of *rotation of crops*. Soils manifestly become exhausted when, by a succession of crops requiring much of some particular substance, that substance is removed from the soil to such an extent that the crop can no longer obtain a sufficient quantity; and the number of crops which a soil will give, depends on the amount of such matter which it originally contained. The particular substance first exhausted will be that which was originally most deficient in the soil, and on which the crop in question makes the greatest demands. Further, the exhaustion of one substance is fatal to the fertility of the soil, especially for such crops as require much of that substance, since the plant cannot, except within very narrow limits, substitute one element for another.

#### § 1. *Causes of Exhaustion.*

Johnston gives the following estimate of the quantity of matter taken from an acre by an ordinary English four course rotation. He supposes that the crop of turnips may amount to 25 tons, that of barley to 38 bushels, that of clover and grass to 2 tons per acre, and that of wheat to 25 bushels,

	Turnip Roots.	Barley.		Clover	Rye Grass	Wheat.		Total.
		Grain	Straw			Grain	Straw	
Potash .....	145.5	5.6	4.5	45.0	28.5	3.3	0.6	239.0
Soda .....	64.3	5.8	1.1	12.0	9.0	3.5	0.9	96.6
Lime .....	45.8	2.1	12.9	63.0	16.5	1.5	7.2	149.0
Magnesia .....	15.5	3.6	1.8	7.5	2.0	1.5	1.0	32.9
Alumina .....	2.2	0.5	3.4	0.3	0.8	0.4	2.7	10.3
Silica .....	23.6	23.0	90.0	8.0	62.0	6.0	86.0	299.2
Sulphuric Acid .....	49.0	1.2	2.8	10.0	8.0	0.8	1.0	72.8
Phosphoric Acid .....	22.4	4.2	3.7	15.0	0.6	0.6	5.0	51.5
Chlorine .....	14.0	0.4	1.5	8.0	0.1	0.2	0.9	25.6

Total pounds.....970.9

If we were to suppose the common four years' rotation of oats, turnips or other green crop, wheat and hay, the result would not be very materially different.

The table shows a loss by cropping in four years of rather less than half a ton of mineral matter from an acre; and if we enquire as to the nature of this loss we find that it might be repaired, if we except the silica, which, being abundant in nearly all soils, may be left out of the account, by the following quantities of mineral manures:

325 lbs. dry Pearl Ash.	150 lbs. Quick Lime.
333 " Carbonate of Soda.	200 " Epsom Salts.
43 " Common Salt.	83 " Alum.
30 " Gypsum.	210 " Bone dust.

These substances would be required to replace those taken away, provided that no part of the crops or the manure derived therefrom should be returned to the soil.

It will be observed that the green crop portion of the rotation carries off the greater part of the mineral substances, and consequently that grain crops are not

the most exhausting to the soil. Practically, however, the difference between a rotation such as this, and no rotation, includes the supposition that manures are introduced with the green crops, whereas where there is no rotation, grain crops are often cultivated for a succession of years without manure.

Whatever the crops cultivated, it is apparent that cropping for successive years without manuring, must ultimately exhaust the soil or render it barren. A very rich soil may long endure such cropping, owing to the great quantity of these substances contained in it; a poor soil will be reduced to sterility sooner; a shallow soil will fail sooner than a deep one, a light soil sooner than a stiff one.

Further, the more available substances in the soil will be exhausted first. The less soluble will remain, and thus a soil may become barren while it still retains much of the food of plants; in this state its productiveness may partially and temporarily be restored by leaving it at rest, and especially by fallowing and tillage, or by ploughing in of green crops, all of which processes tend to set free some of the previously insoluble substances.

If we compare the table of the substances removed by crops with that of the composition of the soil, it is apparent that the exhaustion falls most heavily on some of the substances least abundant in the soil. We cannot exhaust any ordinary soil of silica, alumina, or oxide of iron; nor can a soil naturally calcareous be exhausted of its lime; but there are few soils which can bear several crops without manure and not suffer an appreciable exhaustion of their available phosphates and alkalies. More precisely, we find that the substances necessary to the plant, present in smallest

Total.

39.0  
98.6  
49.0  
32.9  
10.3  
299.2  
72.8  
51.5  
25.6

.970.9

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quantity in fertile soils, and absent or deficient in exhausted ones, are potash and soda, chlorine, sulphuric acid and phosphoric acid. Of these, potash and phosphoric acid are both the most important to the more valuable crops, and the most difficult and costly to procure.

It results that in so far as inorganic matters are concerned, potash and phosphoric acid stand first as of practical importance in the theory of agriculture.

It is observed in practice, especially on those virgin soils rich in vegetable mould, that long cropping deprives them almost entirely of this vegetable mould, and this is sometimes regarded as the sole cause of their impoverishment. In reality, however, it is only a small part of the cause; but it is to be observed that the vegetable mould contains within it a large amount of the material of the ashes of leaves and other vegetable matters which have grown upon the soil, and these are exhausted with the disappearance of the vegetable mould. It may even happen that the forests growing for ages on the soil have drawn up from it nearly its whole stores of available mineral matter and deposited these in the surface vegetable soil. In this case so soon as cropping has exhausted the black mould, the fertility of the soil is gone. But in soils of fertile character it is more usual that much mineral food for plants remains in the soil and subsoil, though often in a state which requires the action of the air for its reduction to a useful state; hence after the vegetable mould has been exhausted by destructive cropping, the land will still yield something after repose or fallowing, or subsoil or trench ploughing.

We must consider here the differences of the *soil*



and *subsoil*. The upper soil may be fertile and the subsoil barren, and *vice versa*. In the former case, crops which spread their roots near the surface, as is the case with the grain crops, will thrive on it, but will exhaust it more rapidly than if the subsoil were fertile. In the latter case, only plants which can send their roots deeply into the soil will succeed well. In the former case, mixing the subsoil with the soil may be injurious, in the latter it may be beneficial.

As the soil becomes gradually poorer under exhaustive cropping, the grain ordinarily becomes short in straw, and the kernel smaller in quantity and poorer in quality. At the same time certain weeds, which still find enough of food in the soil, grow with greater rankness than the crop. Various kinds of parasitic fungi, the mildews, rusts, etc., attack the crop and diminish still further the yield. All these evils are aggravated if the same variety of grain is cultivated without change of seed.\* In these circumstances the uninstructed farmer usually holds that the seasons have become less favorable than formerly, and he is confirmed in this conclusion by finding that in some unusually favorable season he still has a fair crop. He is further confirmed in it when he finds that ploughing in a green crop or adding stable manure, though it increases the straw, does not much improve the grain or rid it of its diseases and enemies; and unless otherwise instructed than by his own experience, he may remain in ignorance of the fact that the ground is exhausted by the loss of the mineral matters he has taken from it in successive crops, and cannot be fertilized except by restoring them to it.

Indeed, his land may be in such a state that in an

soil

unusually favorable season it will produce a good crop, but not in an ordinary season, and since the large crop exhausts it more than the small one, the yield may be even less than usual in the following year. Now, to be profitably cultivated, the land should be in such a state of fertility that it will yield good crops in ordinary years, and that failures should be the exception, not the rule. It is also not unfrequently the case that the unhealthy condition of a plant, depending on deficient nutriment from the soil, is the predisposing cause of diseases and failures. If the soil has the materials of the straw and leaves of wheat, and has not the phosphates required for the grain, the latter cannot be produced; but in this case it usually happens that the plant does not simply wither without producing grain, but that, unable to turn the stores of sugar and albumen it has accumulated to this use, it yields them a prey to the fungi which cause rust, mildew and other diseases; and the loss of the crop is attributed to these, when the primary cause was a partially exhausted condition of the soil. In such a case it is even possible that the straw may be luxuriant without the plant having the means to perfect its seed.

This sad picture of exhaustion applies to large portions of eastern America, and is the principal reason why the wheat culture continually recedes to the west, leaving the exhausted fields to be occupied with buckwheat or other inferior grains.

Some curious cases of special exhaustion of single substances have been observed by chemists. One of these is the removal of phosphates by pasturage. Pasturage is generally supposed to improve rather than to deteriorate the soil. Still the phosphates

removed in the bones and milk of cattle, gradually tell on the quantity of these substances in the soil; and hence, in certain old pastures, beginning to fail, a dressing of bone dust has been found to produce almost magical effects, because it restored the one ingredient, in this case, beginning to be deficient.

It follows from the above statements, that to know the nature, causes and remedies of exhaustion in any particular case, we must study the original composition of the soil, the substances which have been removed from it by cropping, and the best and cheapest way of supplying those which have become deficient.

It also follows that the fertility of the land can be maintained only by restoring to it an adequate amount of the substances of which our crops deprive it, or by rendering fresh quantities of these still in the soil available to plants by tillage, fallowing, etc. This last mode however leads at length to a total exhaustion of the soil, if pursued without recourse to the other. Fortunately for the farmer, the produce which he must sell off the farm does not take away so much inorganic matter as that which he may keep; if, for instance, he disposes only of grain and animal produce, he can keep for the sustenance of the land all the straw, hay, roots, etc., or the manures produced in their use by animals. By a careful economy of these resources in a system of rotation farming, exhaustion may in rich lands be avoided for an indefinite period, though the introduction of additional manures will even in this case be more or less requisite. In China and Japan a scrupulous and painstaking economy of every kind of animal and vegetable manure has maintained the fertility of the soil from

the most remote ages, and will continue to do so, and to support a dense population, for an indefinite period, and this without any knowledge of scientific principles. On the other hand, the neglect of manures in some districts of North America establishes a drain upon the land, which no amount of scientific knowledge can remedy except at very great cost.

### § 2.—*Exhausted Soils of Canada.*

Many very instructive facts in relation to the exhaustion of soils in Canada, are disclosed by the analyses of Canadian soils executed by Dr. Hunt, of the Geological Survey of Canada, and published in the Report of the Survey for the years 1849 and 1850, and also in the general report, in 1863. We shall introduce here a few of these analyses in illustration of the general statements already made.

One of the soils analyzed was a vegetable mould from the alluvial flats of the valley of the Thames in Western Canada, and is said to have yielded 40 or even 42 bushels of wheat to the acre, and in some instances to have been successfully cropped for thirty or forty years without manuring. Dr. Hunt describes this soil as follows:—

“Such is the fertility of the soils in this region that but little need has hitherto been felt of a system of rotation in crops; some, however, have begun to adopt it, and have commenced the cultivation of clover, which grows finely, especially with a dressing of plaster, which is used to some extent.

“The natural growth of these lands is oak and elm, with black walnut and whitewood trees of enormous size; the black walnut timber is already becoming a considerable article of export. Fine groves of sugar

maple are also met with, from which large quantities of sugar are annually made.

"I give here an analysis of a specimen of the black mould from the seventh lot of the first range of Raleigh. The mould here is eight or ten inches in thickness, and had been cleared of its wood, and used six or eight years for pasture; the specimen from a depth of six inches contained but a trace of white silicious sand.

"No. 1 consisted of—

Clay.....	83.4
Vegetable matter .....	12.0
Water.....	4.6
	—100.0

100 parts of it gave to heated Hydrochloric acid—

Alumina.....	2.620
Oxide of Iron and a little Oxide of Manganese...	5.660
Lime .....	1.500
Magnesia .....	1.060
Potash and Soda .....	.825
Phosphoric Acid.....	.400
Sulphuric Acid.....	.108
Soluble Silica.....	.290
	—

This, it will be observed, is a soil rich in alkalies, phosphoric acid, and soluble silica; and on these accounts, eminently adapted for the growth of wheat as well as of nearly all other ordinary crops.

With this may be compared a soil from Chambly, in Lower Canada, respecting which the following remarks are made:

"The soils of this Seigniory are principally of a reddish clay, which, when exposed to the air, readily falls down into a mellow granular soil. In the places where I had an opportunity of observing, it is underlaid at the depth of three or four feet by an exceed-

ingly tenacious blue clay, which breaks into angular fragments, and resists the action of the weather. The upper clays constitute the wheat bearing soils, and were originally covered with a growth of maple, elm and birch; distinguished from them by its covering of soft woods, principally pine and tamarack, is a gravelly ridge, which near the church is met with about fourteen acres from the river; it is thickly strewn with gneiss and syenite boulders much worn and rounded. The soil is very light and stony, but yields good crops of maize and potatoes by manuring."

"The extraordinary fertility of the clay is indicated by the fact that there are fields which have, as I was assured by the proprietors, yielded successive crops of wheat for thirty and forty years, without manure and almost without any alternation. They are now considered as exhausted, and incapable of yielding a return, unless carefully manured; and such, for the last fifteen or twenty years, have been the ravages of the Hessian fly upon the wheat, which is the staple crop, that the inducements to the improvement of their lands have been very small; so that the Richelieu valley, once the granary of the Lower Province, has for many years scarcely furnished any wheat for exportation. But the insect, which for the last three or four years has been gradually disappearing, was last season almost unknown, and the crops of wheat surpassed any for the last ten or twelve years."

"Of a number of soils collected at Chambly, only three have as yet been submitted to analysis; they are—one of the reddish clay taken from a depth of sixteen inches, from a field in good condition, and considered as identical in character with the surface



soil before tillage, No. 2; and one at a depth of six inches, from a field closely adjoining, but exhausted by having yielded crops of wheat for many successive years without receiving any manure, No. 3; the latter supported a scanty growth of a short, thin, wiry grass, which is regarded as indicative of an impoverished soil, and known as *herbe à cheval*; both were from the farm of Mr. Bunker; the third, No. 4, is a specimen of the gravelly loam above mentioned, from an untilled field upon the farm of Mr. Yule."

No. 2 contained a small amount of silicious sand and traces of organic matter, and gave 5.5 per cent. of water.

100 parts of it yielded to heated Hydrochloric Acid:

Alumina.....	3.300
Oxide of Iron .....	8.680
Manganese.....	.160
Lime .....	.711
Magnesia .....	2.310
Potash.....	.536
Soda.....	.340
Phosphoric Acid .....	.418
Sulphuric Acid.....	.020
Soluble Silica.....	.180

No. 3 consisted of—

Silicious sand with a little feldspar .....	9.0
Clay.....	79.2
Vegetable matter .....	6.8
Water.....	5.0
	—100.0

100 parts of it gave—

Alumina .....	not determined
Oxide of Iron.....	4.560
Lime .....	.347
Magnesia .....	.888
Potash }	
Soda }	.380
Phosphoric Acid.....	.126
Sulphuric Acid.....	.031
Soluble Silica .....	.080



By the action of water, a solution containing minute traces of chloride and sulphates of lime, magnesia and alkalies is obtained. 100 parts of the soil give in this way, of chlorine, .0013; sulphuric acid, .0005.

No. 4. This soil contained about 20 per cent. of pebbles, and 12 of coarse gravel: that portion which passed through the sieve consisted of—

Gravel.....	75.0
Clay.....	13.7
Vegetable matter .....	6.1
Water.....	5.2
	—100.0

The soil was very red, and the sand silicious and quite ferruginous, consisting of the disintegrated syenitic rocks which make up the coarser portions.

100 parts gave—

Alumina .....	2.935
Oxide of Iron.....	5.505
Lime .....	.156
Magnesia .....	.409
Potash.....	.109
Soda.....	.144
Phosphoric Acid.....	.220
Sulphuric Acid.....	.018
Soluble Silica.....	.080

The first of these soils, (No. 2) that which had not been exhausted, closely resembles in its proportions of inorganic plant-food that first noticed. It is further to be observed, that while one of these soils, that from Raleigh, is very rich in vegetable matter, and the other, that from Chambly, contains very little, both are equally fertile as wheat soils. This is a striking evidence of the great importance of the mineral riches of the soil.

If now, we compare the fertile soil No. 2, with the

exhausted soil No. 3, we see at once that the latter has parted with the greater part of its alkalies and phosphoric acid, and probably with the more available part of these substances. The exhaustion of potash and phosphates is, in truth, the cause of its present sterility; and when we consider that the straw and grain of thirty crops of wheat have been taken from it without return, we have sufficient reason for the change.

The third soil, No. 4, characterized as of light quality, is, in comparison with No. 2, poor in lime, phosphates, alkalies, and soluble silica, but it has nearly twice as much phosphoric acid as the worn out soil, No. 3, and is not behind it in soluble silica. An equal quantity of ordinary manure would probably produce more effect on it than on the exhausted soil No. 3.

Another term of comparison is afforded by a soil from the farm of Major Campbell, at St. Hilaire, which is said to have been reclaimed from comparative exhaustion by manuring and draining. It is a heavy clay, and afforded, on analysis, in 100 parts:

Alumina.....	12.420
Oxide of Iron .....	7.320
Lime .....	.697
Magnesia .....	1.490
Potash.....	.591
Soda .....	.231
Phosphoric Acid .....	.390
Sulphuric Acid.....	.022
Soluble Silica .....	.105

This soil, it will be observed, rises very nearly to the level of the unexhausted soil from Chambly; and the difference between it and the exhausted soil, No. 3, is, no doubt, due to the manures added by the

proprietor, and to the admixture of unexhausted subsoil by draining and deeper ploughing.

That this last cause had some share in this result is indicated by an analysis of subsoil, taken from the same field, but at a depth of thirty inches from the surface. No manures penetrate a clay soil to such a depth as this, so that this analysis gives the natural quality of the soil. It shows in 100 parts :

Alumina .....	4.380
Oxide of Iron .....	6.245
Lime .....	.980
Magnesia .....	1.080
Potash.. .....	.753
Soda .....	.355
Phosphoric Acid .....	.474
Sulphuric Acid.....	.024
Soluble Silica .....	.210

It thus appears that the subsoil is far richer than the improved surface soil in alkalies, phosphates, and soluble silica. The subsoil is a vast store of mineral manure, ready to be applied to use by under-draining and subsoil ploughing. It would seem that this applies very generally to the exhausted clay soils of Canada, which, having been undrained, ploughed in a shallow manner, and cropped by plants which feed in these circumstances only on the surface soil, might be renovated by tile draining and the use of the subsoil plough more easily than by the application of manurial substances. This is a fact which holds forth a gleam of hope for all the impoverished farms of the older and exhausted districts.

It is to be observed, however, that the material of the subsoil probably requires some tillage and aëration to make its constituents available for plants, so that it should be very gradually mixed with the surface

soil. It would also require the addition of some organic matter, as, for instance, peat or bog mud.

In leaving these Canadian soils, it is deserving of remark, that even the richest of them are rather poor in sulphuric acid, and would, therefore, probably be benefited by the use of gypsum.

It must also be observed that the exhaustion of soils is not to be accounted for simply by the removal of mineral matters. The soil, as already stated, is the storehouse from which many plants derive the greater part of that indispensable substance nitrogen. In the husbandry of nature which carefully returns to the soil the *débris* of life, and which mingles on each foot of ground in proportions determined by the needs of the case, plants of many divers species continually supplanting each other in a ceaseless rotation, the store of nitrogen is constantly replenished, but when a farmer removes from the same field the same crop of grain year after year without adequate manure, he not only exhausts the soil of its mineral wealth, but he reduces it to infertility by depriving it of available nitrogen.

## CHAPTER XIII.

### IMPROVEMENT OF THE SOIL BY MECHANICAL MEANS.

Amelioration of the soil may be mechanical, by acting on its texture and its relations to water and the air, or chemical, by adding to it nutritive substances. The former only will be considered in this place. The latter will come more naturally under the head of manures.

#### § 1. Tillage

Several methods of improving the mechanical condition of the soil are within the reach of the farmer.

One of these is the ancient and most important expedient of *tillage*. The stirring and loosening of the soil by the plough, the spade, the harrow, the subsoil plough, and other implements, are not merely necessary preparations for the seed, but important means of ameliorating the soil. The chemical changes proceeding in the soil, by which food is prepared for plants, require the presence both of air and water. The larger pores of the soil must be filled with air, the smaller with water. This is the condition of a mellow, well prepared soil. It is the condition most favourable to the germination of seeds and the penetration of roots, as well as to the complex chemistry of the soil itself. The roots of a crop exhaust the soil in their vicinity, while other portions remain untouched; but tillage mixes the whole again, and gives the roots of the succeeding crop a better opportunity of extracting nutriment.

Again, there are in most soils small fragments of vegetable and mineral matter, which, if exposed to the action of the air and moisture, would yield up their constituents as food for plants. Tillage enables them to do so. Hence the maxim of some farmers that much and careful tillage is equivalent to manure. Hence also the benefit of fallowing, which not merely allows the soil to rest, but brings into use its reserve stores of nutriment.

We must, however, beware of supposing that tillage actually enriches the ground, or of falling into the error of those writers who maintain that nothing else is necessary to fertility. The manurial value, so to speak, of tillage, depends essentially on its power of rendering serviceable the insoluble portions of the soil; and when these are exhausted by a long course of cropping, tillage or fallowing will fail to be of service any longer in this respect. Even in this case, however, if the surface soil only is exhausted, subsoil and trench ploughing may bring a new soil within reach of plants, and by rendering its stores accessible, prolong for some time, though not for ever, the fruitfulness of the soil.

The chief implements of manual tillage are the spade or the digging fork, the rake and the hoe. The spade or the digging fork are employed to loosen and to invert the top layer of the soil, to form beds, to throw up ridges of soil, or to trench the land more or less deeply. The loosening of the soil admits air and moisture to it, and enables the rootlets of plants to penetrate it more easily in all directions. The inverting of the soil buries weeds, turns under the upper more highly oxidized layers of the soil, and brings up the lower layers to be acted on more

immediately by the air. Beds elevated above the general surface of the garden are thereby rendered somewhat drier than the general mass of the soil, and are most frequently resorted to in rainy climates, and in low undrained soils. Ridges are frequently thrown up at the approach of winter in order that the clods may be disintegrated, and the soil rendered friable by frost. The trenching of land, which is essentially a disturbance of the subsoil two or three spades deep, may be so conducted as merely to loosen the subsoil and make it accessible to the roots of plants. Or, again, it may be so managed as to bring up from beneath and mingle with the upper soil more or less of the subsoil. Whether it is wise to do this or not will be determined by the character of the subsoil. The digging fork penetrates hard ground more easily than the spade, and it loosens wet ground more effectively, not compacting it so much. The use of the rake is to follow the spade, removing weeds and stones, breaking up clods which have escaped the pulverizing action of the spade, and levelling the minute inequalities of surface. The common hoe and the scuffle hoe, or Dutch hoe, especially the latter, are excellent exterminators of weeds, and both loosen the topmost layer of the soil. But the common hoe is the more serviceable in hilling up potatoes and corn.

No farm implements for the purpose of tillage, operated by horses or by steam, can quite equal in effectiveness the hand tools just described. But ploughs, harrows, horse-hoes and rollers are no mean substitutes for them.

The common plough consists essentially of *a*, the beam, to which all other parts are fastened; *b*, the coulter, a sort of perpendicular knife, which cuts the



furrow-slice off vertically; *c*, the share, a triangular horizontal knife, set at the deepest part of the plough to cut off the sole of the furrow slice; *d*, the mould board, or breast, a twisted surface behind the coulter



Fig. 6.

which gradually turns the furrow slice over; *e*, the head of the plough, to which the draft-chain is fastened to pull the plough through the

soil; *f*, the stilts or handles, by which the ploughman guides it, regulating both the depth and the width of the furrow.

Many refinements of design and make, not above described, tend to the perfecting of this most important of agricultural implements. An adjustable wheel or wheels sometimes carry the front of the beam and serve to govern the movement of the plough so as to secure the cutting of a furrow slice constant in width and depth. The brake or clevis at the head of the plough, to which the draught chain is attached, admits a right or left and an up or down adjustment so as to cause the plough to cut a wider or a narrower, a deeper or a shallower furrow. Sometimes a skim-coulter, which is like a miniature plough, is fastened to the beam in front of the coulter. Its purpose is to turn the top layer of the soil with weeds and manure that has been spread on the surface, into the bottom of the furrow, to be buried under the furrow slice.

Ploughs are modified for special purposes, as the ridging plough and the side hill plough. Most important of all the special purpose ploughs is the subsoil plough. This plough is intended to run behind a common plough in the same furrow, splitting

and slightly raising but not throwing up to the surface nor inverting the subsoil. One of the best forms of the subsoil plough consists of a beam with its clevis in front and handles behind, to the under side of which is fastened, by two perpendicular steel standards, an arrow head of steel laid flat, with its point set in front. The forward standard presents a cutting edge. The arrow head is flat on the under side, but rises backward into a convex wedge. Such an arrow head, 12 inches long, 8 inches broad, and rising to 3 inches thick in the middle of the back, forced through the subsoil at a depth of from 6 inches to 18 inches beneath the bottom of an ordinary furrow, has an extraordinary effect in breaking up hard pan, in loosening the subsoil and in deepening the available soil without throwing the raw subsoil up to mingle with the surface layers.

The horse hoe or cultivator appears in farm practice under many forms. It is essentially a frame work, partly or wholly carried on wheels, armed beneath with long perpendicular standards ending in teeth or in cutting blades that scarify the earth from one to four inches deep, cutting off weeds and loosening the very surface of the earth so as to admit air and hinder evaporation. In order to fit the cultivator for many uses it is often provided with many forms of interchangeable teeth or blades.

Harrows in field culture serve the purposes for which the rake is used in gardening. The harrow consists of a frame-work of one piece, or preferably of more than one piece hinged together, so as to be somewhat flexible and capable of accommodating itself to inequalities of surface, furnished with many spikes projecting beneath. As this implement is

dragged over ploughed land it combs off the projecting edges of the furrows as left by the plough; it levels the surface; it breaks down clods; it teases out weeds; it raises stones to the surface; and leaves the ground mellowed and pulverized to the depth of two or three inches. Also after the broadcasting of seed, it buries the seed just beneath the surface, hiding it from the light and from birds, and bringing it within the influence of capillary moisture rising from the deeper moist layers of the earth. A good harrow has a very flexible frame, as light in weight as is consistent with covering a sufficient width of ground and sinking the harrow deep enough for its work, and its teeth are so disposed in the frame that no tooth follows in the track of another, and that the ground passed over by the harrow is combed by many little equidistant furrows.

The roller most frequently used is specially designed for smoothly compressing the surface of the soil about the seed when newly sown, and is usually a smooth cylinder of cast iron revolving on an axle; but it is better made in sections as though built up of four or more very broad-faced cast iron wheels of equal size revolving on a common axle.

The plough is used to invert the soil in preparation for a new crop. When sod is broken up it is desirable to turn under the upper layer which contains grass, weeds and their seeds, in order that the vegetation that is to be replaced may be destroyed. For this purpose the breaking plough is employed, making the breadth of the furrow-slice at least twice its depth; the sod is then inverted, its grass side rots, and the roots turned upward die, killed by the action of the sun and wind. In fall ploughing with the

common plough, preparatory to spring work, it is best to throw up the furrows in little ridges that may crumble down in the frost. This is best done by making the depth of the furrow-slice about two-thirds of its breadth. The furrow-slice will then be turned through one right angle and a half, ( $135^{\circ}$ , three-fourths inverted), and the angle formed by the meeting of the inner face, and the bottom of each furrow-slice will be thrown directly upward, so as to cover the field with longitudinal right-angled ridges, exposing to the action of the weather the largest possible amount of surface, and admitting air freely to the corresponding longitudinal hollows left empty between and under the furrow-slices. It must be remembered, however, that in a field ploughed in this manner, if the soil be so coherent that the furrow-slices retain their form, the capillary connection between the ploughed layer and the subsoil is to a great extent cut off. Water will rise very slowly from the subsoil into the ploughed layer, so that the latter is dependent for moisture on showers. Such ploughing is more suitable, therefore, in fall than in spring. The winter rains and frosts will crumble and compact the ploughed layer, so as to restore capillary contact with the subsoil before the seed is sown in the spring. But if ground be so ploughed in the spring and immediately sown, and dry weather follow, germination is delayed and young plants are stunted in growth through lack of moisture. Of course cross ploughings, and the use of the cultivator and the roller, crumble the soil, fill in the hollows underneath the ploughed land, and restore capillary connection.

Ploughing, and indeed every kind of tillage, is

injurious to tenacious soils while so wet as to be in a plastic condition. Then the trampling of horses and of men and the compressive action that necessarily attends the use of every instrument of tillage, knead the soil into resistant clods that long refuse to admit the entrance of rootlets. Heavy clay lands, although usually rich in the inorganic food of plants, have this great disadvantage, especially when undrained, that they are accessible for tillage during a much smaller part of the year than lighter soils. When the weather is dry, they are so hard as to be all but impenetrable by the plough; when it is wet, the soil if worked kneads into bricks; and, besides, after being soaked by rains they retain the water with which they are charged so tenaciously that it is long before they come into condition for working. In these heavy soils the constant traverse of the sole of the plough at a nearly uniform depth forms a hard pan of great compactness, which neither moisture nor roots can easily penetrate. The use of the subsoil plough is here indicated.

Before seed is sown implements of tillage are used to reduce the soil to a state of fine tilth; that is to a loose, granular condition, in which there are innumerable pores filled with air; the granules neither crumbling down into a fine compact dust that the first rain will make into an air-proof mortar, nor adhering to each other in stony clods; the capillary connection with the subsoil being maintained so that without having the air contained in it replaced by water, the upper soil may nevertheless be kept moist.

When seed is sown by hand, the harrow is used to cover it and the roller to restore the capillary connection broken by the harrow.

When seed is broadcast or drilled in close drills, so that the crop covers the ground, tillage ceases till the crop is harvested. But when the crop is sown in wide drills or hills, as root crops and corn, as soon as the young plants can be distinguished, or even earlier, shallow cultivation with the horse hoe or cultivator begins. The stirring of the upper layers of the soil between the rows of plants contributes greatly to the luxuriance of vegetation, especially in dry weather; this for two reasons, first, the weeds which compete with the crop for nourishment from the ground are destroyed; secondly, the capillary connection between the lower and the topmost layers of the soil is interrupted, so that moisture is not evaporated from the unoccupied surface, and that part of the land from which the crop derives its nourishment is kept both moist and warm. Such cultivation must, however, be shallow, or it will destroy many spreading rootlets of the crop.

## § 2. Draining.

One most important mode of ameliorating the soil is under-draining by tiles and similar contrivances. No expedient has proved so serviceable in improving the mechanical qualities of the soil; and even in warm and dry climates like that of Canada, it has been found most profitable by all who have skilfully employed it. Its various beneficial effects may be shortly summed up as follows:—

It makes the soil warmer, by draining off the water which otherwise would keep the ground cold by its evaporation. Land under-drained is sometimes from 10° to 15° warmer than similar undrained land lying adjacent to it. For this reason, and because the soil



being sooner rid of surface water, is more quickly ready to endure the trampling of men and horses without poaching, it enables the ground to be worked earlier in spring and later in autumn, and renders the growth of crops more rapid.

It tends to prevent the surface from being too much washed by rain ; as it enables the water to penetrate the soil, carrying downward the substance of rich manures, instead of washing it to lower levels. It thus, in connection with that absorbing power of the soil already described, saves the riches of the soil from waste.

It allows the roots of plants to penetrate deeply into the soil, instead of being stopped, as they often are, at the depth of a few inches, by a hard subsoil, or by ground saturated with water, or loaded with substances injurious to vegetation. For this reason, drained lands stand drought better than undrained, and their crops are also larger and more healthy. Hence also it often happens that draining benefits even light lands, if they happen to have an impermeable subsoil.

It permits free access of air, thus preventing the "souring" of the soil, and bringing manures of all kinds into a fit state for absorption by the roots.

It prevents injury to the soil from the water of springs coming from beneath by capillary attraction. It also prevents baking in dry weather, and causes the ground to crumble more freely when ploughed.

It tends to diminish the effect of frost in throwing out the roots of clover and grasses, by enabling the roots of these plants to take a deeper hold of the soil.

In short, it renders land easier and more pleasant to work ; makes crops more sure and heavy ; prevents



alike injuries from drought and excessive moisture ; economizes manures ; and is equivalent to the deepening of the soil, and the lengthening of the summer.

The following short summary of the methods of under-draining is taken from "Norton's Elements of Scientific Agriculture."

"First, as to depth ; where a fall can be obtained, this should be from 30 to 36 inches. The plants can then send their roots down, and find to this depth a soil free from hurtful substances. The roots of ordinary crops often go down three feet, when there is nothing unwholesome to prevent their descent. The farmer who has a soil available for his crops to such a depth, cannot exhaust it so soon as one where they have to depend on a few inches, or even a foot of surface. Manures, also, cannot easily sink down beyond the reach of plants. On such a soil, too, deep ploughing could be practised, without fear of disturbing the top of the drains. The farmer should not, by making his drains shallow, deprive himself of the power to use the subsoil plough, or other improved implements that may be invented, for the purpose of deepening the soil. There are districts in England, where drains have had to be taken up and relaid deeper, for this very reason. It would have been an actual saving, to have laid them deep enough at the first.

"Second, as to the way in which they should be made, and the materials to be used."

"The ditch should, of course, be wedge-shaped, for convenience of digging. The bottom of it need only be wide enough to receive the tiles. The upper part of the earth is taken out with a common spade, and the lower part with one made quite narrow for the

purpose, being only about four inches wide at the point. The bottom is finished clean and smooth, with a peculiar hoe or scoop. This is necessary, because the tiles must be laid on an even smooth foundation."

Of all materials that have been used in the construction of drains it is now found that tiles, made of clay and burned, are cheapest. These have been made of various shapes.

"The first used was the horse-shoe tile. This was so named from its shape; it had a sole made as a separate piece to place under it, and form a smooth surface for the water to run over.

"Within a few years this tile has been almost entirely superseded by the pipe tiles (which are merely earthenware pipes, of one inch bore or larger, and made in short lengths). These tiles have a great advantage over the horse-shoe shape, in that they are smaller, and are all in one piece; this makes them cheaper in the first cost, and also more economical in the transportation.

"All these varieties are laid in the bottom of the ditch, it having been previously made quite smooth and straight. They are simply placed end to end, then wedged a little with small stones, if necessary, and the earth packed hard over them. Water will always find its way through the joints. Such pipes, laid at a depth of from  $2\frac{1}{2}$  to 8 feet, and at proper distances between the drains, will, in time, dry the stiffest clays. Many farmers have thought that water would not find its way in, but experience will soon show them that they *cannot keep it out*. The portion of earth next the drain first dries; as it shrinks on drying, little cracks begin to radiate in every direction, and to spread until at last they have

penetrated through the whole mass of soil that is within the influence of the drain, making it all, after a season or two, light, mellow and wholesome for plants."

"They form a connected tube, through which water runs with great freedom, even if the fall is very slight. When carefully laid, they will discharge water, where the fall is not more than two or three inches per mile. If buried at a good depth, they can scarcely be broken; and if well baked, are not liable to moulder away. There seems no reason why well-made drains of this kind should not last for a century. The pipe tiles are used of from 1 to  $1\frac{1}{2}$  inches diameter of bore for the smaller drains, and for the larger, up as high as 4 or 5 inches. They are all made in pieces of from 12 to 14 inches in length. An inch pipe will discharge an immense quantity of water, and is quite sufficient for most situations. These small drains should not ordinarily be carried more than 400 to 500 feet before they pass into a large one, running across their ends. Where a very great quantity of water is to be discharged, two large-sized horseshoe tiles are often employed, one inverted against the other.

"Third, as to the direction in which the drain should run. The old fashion was to carry them around the slopes, so as to *cut off* the springs; but it is now found most efficacious to run them *straight down*, at regular distances apart, according to the abundance of water and the nature of the soil. From 20 to 50 feet between them would probably be the limits for most cases. It is sometimes necessary to make a little cross-drain, to carry away the water from some strong spring. In all ordinary cases, the

drains running straight down, and discharging into a main cross-drain at the foot, are amply sufficient."

For connecting the consecutive lengths of pipe collars are sometimes used. These are very short pipes, in which the diameter of the bore is equal to the outer diameter of the pipes to be connected. The adjacent ends of these pipes are thrust into the collar, which serves to prevent, almost completely, the entrance of silt at the junction.

As, however, silt cannot be completely excluded, the pipes used in drainage should be as small as will carry off the water, in order that they may be effectively scoured by the current through them; they must be most carefully laid with a uniform fall, and should be joined with the larger pipes at a small angle, by the use of junction pipes, in order that there may be no places of slack current in which the silt may be deposited; and where una-

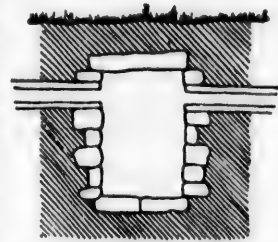


Fig. 7.

avoidable abrupt changes of direction or of slope take place, there silt basins should be established. These silt basins may be constructed of wood, of brick or of stone, or they may be merely larger earthenware pipes set on end, the general plan of construction being readily understood from the marginal figure, which represents two drain pipes, one entering and the other leaving the silt basin. It is clear that much of the earth brought down by the entering pipe will settle in the silt basin, which must be cleared out from time to time. The silt basin may be built up to the surface and there carefully covered, or it may be covered at about the level of the drain with a board

or a stone, and the earth filled in above it, its position being, of course, exactly noted. The exit of the whole system of drainage should be carefully built, and the mouth covered with an iron grating to prevent the entrance of vermin.

Before commencing to lay drains, the whole land to be drained should be carefully mapped out, with contours of elevation drawn. The system of drainage should then be determined, fully and accurately marked on the plan with the position of every smaller and larger drain and silt basin carefully laid down. The plan should then be exactly followed and preserved for future reference.

With regard to these mechanical modes of improving the soil, it may be stated with truth—

1. That except in some cases of naturally deep and well-drained soils, no soil has a fair chance of showing its capabilities without deep ploughing and draining.

2. That many partially exhausted soils may have their fertility restored by these processes.

3. That the deepening and loosening of the soil occasion no waste of manures, but the reverse.

4. That when judiciously conducted these improvements have proved themselves to be among the cheapest and most profitable that can be attempted.

In estimating the cost of underdraining, it will be borne in mind that the price of tiles will differ in different localities and that their cost to the farmer will depend on his distance from the kilns. Again the cost of laying will be less where skilled labour can be secured, even at much greater daily wages. In the examples that follow the cost of tiles without collars is reckoned at 25 cents a rod, with collars at 30 cents a rod. The cost of laying is estimated at

50 cents a rod four feet deep, 47 cents three feet six inches deep, 43 cents three feet deep, and 38 cents two feet six inches deep.

*Examples.*

161. How many rods of drain will be required to drain a ten acre square field, the first drain being one rod from and parallel to one side and the other drains parallel to it and two rods apart?

162. How many, if the first drain be 15 feet from one side, and the others 30 feet apart?

163. How many, if the first drain be 10 feet from the side, and the others be 40 feet apart?

164. What will it cost to drain each field as described in the three preceding examples, both with and without collars and at each of the depths, 4 feet, 3 feet 6 inches, 3 feet and 2 feet 6 inches?

165. How much will it cost to lay parallel drains without collars, four feet deep and one rod apart in a square 40 acre field, the first drain being parallel to one side and eight feet distant from it?

166. What will it cost to drain a rectangular field of 16 acres, one side to which the drains are parallel being 50 rods long; the drains are to be three feet deep and 30 feet apart, the first one being 12 feet from the side of the field; the pipes are to have collars?

167. If the total cost of draining one acre be \$85, if the net annual return from the land be \$10 more after draining, and if the deterioration of the drain be  $2\%$  of its cost annually, what per cent. does the farmer get on the cost of draining?

168. Suppose that on undrained land a farmer can raise per acre in successive years 22 bushels of wheat,

one ton and a half of hay, pasturage for one year at the rate of two cows on three acres, 35 bushels of oats and 175 bushels of potatoes; while on drained land he can raise 27 bushels of wheat, two tons of hay, pasturage for one year at the rate of eight cows on nine acres, 50 bushels of oats and 200 bushels of potatoes; if wheat be 80 cents a bushel, oats 33 cents, potatoes 35 cents; if hay be \$10 a ton and the pasturage of a cow for one season be worth \$6; if the deterioration of the value of a drain be  $2\frac{1}{2}\%$  annually; and if, finally, it be held that the greater ease of working will compensate the cost of harvesting and manuring for greater crops; will it pay a farmer to borrow money at  $6\%$  to drain his land 3 feet deep, drains being on the average 40 feet apart and being without collars? What per cent. on the borrowed capital would he have each year for himself, and what additional annual income would he have from a farm of 100 acres so treated?



## CHAPTER XIV.

### IMPROVEMENT OF THE SOIL BY MANURES.

#### § 1. *General Nature of Manures.*

Any substance added to the soil by the farmer for its improvement, or the sustaining of its fertility, may be considered as a manure. Such substances may be regarded from different points of view, according to their origin, nature and uses.

Some manures are supplied by animal and vegetable substances, others by mineral substances; hence the distinction arises of *organic manures* and *inorganic manures*.

Some are *produced on the farm*, from the crops it has yielded, and their application only restores what has been taken away; others are obtained *from abroad*, and so are actual additions to the soil.

Some act *directly* as food to plants, others also *indirectly*, by making other substances useful; and they may do this either by rendering insoluble matters soluble or, on the other hand, by fixing in the soil substances which might escape from it in a volatile state. For instance, gypsum may act directly by affording sulphuric acid and indirectly by fixing ammonia.

Some are *general* manures, that is, they are more or less beneficial on all soils and to all plants. Of this kind are the ordinary stable manures and composts. Others are *special*, with reference to particular soils needing them, or with reference to particular kinds

of plants. Of this kind are such substances as nitrate of soda, gypsum and superphosphate of lime.

Some afford nourishment principally to the *organic* part of plants; and of this kind the most important are those which can supply ammonia and carbonic acid. Others afford the materials of the *inorganic* part of the plant; and of this kind are the various mineral manures, ashes and some kinds of guano.

In considering any manure, it is necessary to have regard to all these various uses, if we would wish to estimate its value or understand its action. For the present purpose we shall class manures as organic and inorganic, and shall notice under each its relations to various soils and plants.

Under the head of organic manures I group all those fertilizing substances which have formed parts of animals or plants, and are restored to the soil, whence, or by the aid of which, they were obtained; though some of them cannot, in strict chemical language, be termed organic.

## § 2. *Stable Manure.*

Eighty years ago one of the ablest of British American agriculturists said, "More than one-half of the manure made in the provinces is absolutely wasted from ignorance and inattention; and the other half is much less productive than it would have been under more skilful direction. We have almost no pits dug upon a regular plan, for the collection and preservation of the dung which, from time to time, is wheeled out of the barn. Sometimes it is spread out on the green sward; sometimes cast carelessly in a court or adjoining yard; but seldom is an excavation made purposely for retaining the juices which run

from it. These are suffered either to stream along the surface or sink into the earth; and in either case, their utility is sacrificed to inattention or ignorance. This is no more, however, than half the evil. The exhalations which arise from the ardent influence of the summer's sun or from the natural activity of fermentation, are permitted to escape freely and to carry with them all the strength and substance of the putrescible matter."\*

There is, no doubt, much more attention given to this important subject now; but still, the waste of barn-yard manure, both solid and liquid, is a great evil and a fruitful cause of agricultural poverty and failures of crops. Some years ago, I had referred to this subject in a public lecture, and happened, immediately afterward, to drive ten or twelve miles into the country, with an intelligent friend, who doubted the extent of the loss. We were driving through an old agricultural district, and, by way of settling the question, determined to observe the capability of each barn-yard that we passed, for the preservation of manure. It was early in the spring, and we found scarcely one barn that had not its large manure heap perfectly exposed to the weather, and with a dark stream oozing from its base into the road-side ditch, or down the nearest slope; while there was evidently no contrivance whatever for saving the liquid manure of cattle. Here was direct evidence, that a large proportion, probably not less than one-third, of the soluble part of the solid manure, and the whole of the liquid manure, which all agricultural chemists think to be at least equal in value to the solid part, was being lost. In other words, each farmer was deliber-

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\*Young's "Letters of Agricola," Halifax, 1822.

ately losing between one-half and two-thirds of the means of raising crops, contained in his own barn-yard. What should we think of a tradesman or manufacturer, who would carelessly suffer one-half of his stock of raw material to go to waste? And the case of such farmers is precisely similar. The results of chemical analysis will enable us to form more precise ideas of the nature and amount of this waste.

In a prize essay on manures, by Prof. Way, published by the Royal Agricultural Society of England, the following analysis is given of the drainings of a dung-heap, composed of the mixed manures of horses, cattle and sheep, and in a well rotted condition. The fluid examined was that washed out by rain water, and was of a deep brown color. It contained in each imperial gallon 764.64 grains of solid matter, of which 395.66 were volatile and combustible, and 368.98 incombustible or ashes. Its composition was as follows:—

#### I. COMBUSTIBLE PART.

Ammonia in a soluble state .....	36.25
Ammonia in fixed salts .....	3.11
Ulmic and humic acids.....	125.50
Carbon dioxide.....	88.20
Other organic matters (containing 3.59 of Nitrogen).....	142.60
	<hr/> 395.66

#### II. INCOMBUSTIBLE PART.

Soluble silica .....	1.50
Calcium phosphate with a little iron phosphate.....	15.81
Calcium carbonate.....	34.91
Magnesium carbonate .....	25.66
Calcium sulphate.....	4.36
Sodium chloride .....	45.70
Potassium chloride .....	70.50
Potassium carbonate.....	170.54
	<hr/> 368.88

Total per gallon .....764.64

An examination of this analysis shows that each ton of this liquid contained a little less than 1 lb. of nitrogen, something more than 4 lbs. of potash and about a quarter of a pound of phosphoric acid ; the value of the liquid was about 38c. a ton.

An analysis by Dr. Voelcker of stable manure, consisting of a mixture of horse, cow and pig manure, may be taken as representing the average composition of manure fourteen days old. It shows that one ton of stable manure, such as he analysed, consists of

Water .....1323 lbs.

#### SOLUBLE ORGANIC MATTER.

Nitrogen ..... 3 lbs.

Other matters .....46.6 "  


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 49.6 "

#### INSOLUBLE ORGANIC MATTER.

Nitrogen..... 9.9 lbs.

Other matters .....505.3 "  


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 515.2 "

#### INORGANIC MATTER.

	Soluble.	Insoluble.	Total.
Potash.....	11.5 lbs.	2 lbs.	13.5 lbs.
Soda.....	1.3 "	.4 "	1.7 "
Lime.....	3.7 "	22.4 "	26.1 "
Magnesia ..	.2 "	2.9 "	3.1 "
Silica ..	24.1 "	11.2 "	35.3 "
Chlorine ..	.4 "		.4 "
Sulphuric acid..	1.1 "	1.2 "	2.3 "
Phosphoric acid	3.6 "	3.6 "	7.2 "
Oxide of iron, alumina, carbon dioxide and loss.....			22.6 "
			<hr style="width: 10%; margin-left: 625px;"/> 112.2 "
			<hr style="width: 10%; margin-left: 625px;"/> 2000.0 "

If, as is customary, we value this manure by its content of nitrogen, potash and phosphoric acid alone

it is worth for its soluble nitrogen at 15c. a pound, 45c.; for its insoluble nitrogen, at 5c. a pound, 49½c.; for its potash, at 5c. a pound, 67½c.; and for its phosphoric acid at 10c. for soluble and 5c. for insoluble, 54c.; \$2.16 a ton. The value of its remaining inorganic ingredients is insignificant. Silica is so abundant in all soils as to be practically worthless, and all other of the remaining ingredients could be furnished for less than 10c. It is impossible to value the 550 lbs. of organic matter which is not nitrogen, for want of a definite standard. This organic matter not only ministers directly to the growth of plants as plant food, but it much ameliorates the physical condition of the soil, and plays an important, though as yet ill-understood, part in maintaining the bacterial life of the soil, on which many important processes of nitrification and fermentation are dependent. But no money value can as yet be assigned to these services.

Liquid stable manure is a fertilizer of great value as will appear from the following table:—

*Composition of Liquid Stable Manure (Boussaingault).*

	Horse.	Cow.
Urea .....	31.00	18.48
Potassium hippurate.....	4.74	16.51
Potassium lactate .....	20.09	17.16
Magnesium carbonate .....	4.16	4.74
Calcium carbonate.....	10.82	0.55
Potassium sulphate .....	1.18	3.60
Sodium chloride.....	0.74	1.52
Silica .....	1.01	—
Water, &c .....	926.26	937.44
	<hr/>	<hr/>
	1000.00	1000.00

Urea, as appears from its formula,  $\text{CH}_4\text{N}_2\text{O}$ , is very rich in nitrogen. In decomposing, it changes into carbonate of ammonia, which, being volatile,

rapidly escapes, unless prevented by some absorbent material, as charcoal, or by the chemical action of sulphuric acid or gypsum.

A similar statement may be made respecting hippuric acid of which the formula is  $C_9H_9NO_3$ ; the results of its decomposition are, however, more complex than those of urea.

In the above table, we see that the liquid manure contains large quantities of potash and soda; and that a large portion of it is urea, a substance which from its abundant nitrogen is, in fact, quite similar to the richest ingredients of guano. Johnston estimates the value of 1,000 gallons of the urine of the cow to be equal to that of a hundredweight of guano. The farmers of Flanders,—who save all this manure in tanks,—consider the annual value of the urine of a cow to be \$10.

One ton of liquid horse manure contains 29·8 lbs. of nitrogen, and 15 lbs. of potash; that of the cow 19·4 lbs. of nitrogen, and 19·7 lbs. of potash. On the presence of these substances their manurial value largely depends, for phosphoric acid is but an insignificant constituent of the urine of horses and cattle. One ton of liquid horse manure is worth \$5·22, and of liquid cow manure \$3·90.

In the solid manure there is little nitrogen. This element, so valuable for producing the richer nutritious parts of grain and root crops, is principally found in the liquid manure. The little that is present, however, in the solid manure, is soon lost in the form of ammoniacal vapours, if the dung be allowed to ferment uncovered. The other organic matters are less easily destroyed, unless the dung be allowed to become "fire-fanged," in which case the greater part



of it is lost. In the ashes, or inorganic part, we find all the substances already referred to as constituents of fertile soils; and many of the most valuable of them are, as the manure decomposes, washed away, and, along with a variety of organic matters, appear in the dark-colored water which flows from exposed dung-hills. It is not too much to say that the loss of the volatile and soluble parts of manures, on ordinary upland soils, cannot be repaid by any amount of outlay in the purchase of other manures, that our farmers can afford; and we can plainly perceive, that the prevailing neglect in this one particular, is sufficient to account for the deterioration of once fertile farms. How, then, is this waste to be prevented? In answer to this, I shall merely indicate the principles on which the means adopted for saving manures are founded, with a few general hints on the best modes of carrying them into effect.

1. The solid manure should be covered with a shed or roof, sufficient to protect it from rain and snow. Its own natural moisture is sufficient to promote, during winter, a slow and beneficial fermentation. Snow only prevents this from going on; rain washes away the substance of the fermented manure.

2. The ground on which the manure heap rests should be hollowed, and made tight below with clay or planks; and in autumn, a thick layer of bog mud, or loam, should be placed on it, to absorb the drainings of the manure.

3. When the manure is drawn out to the field, it should be covered as soon as possible, either in the soil, or, if it must stand for a time, with a thick coating of peat or loam,—a pile of which should be prepared in autumn for this purpose. All unnecessary exposure should be avoided.

4 Where gypsum can be procured cheaply, it should be strewed about the stables, and on the manure heap, for the purpose of converting volatile ammoniacal vapours into *fixed* sulphate of ammonia. This will also render the air of the stables more pure and wholesome.

5. It must be borne in mind that the richest manures are the most easily injured. For example, many farmers think horse manure to be of little value. The reason is, that when exposed it rapidly enters into a violent fermentation and decay, and its more valuable parts are lost. Such manures need more care than others, in protection and covering, so as to moderate the chemical changes to which they are so liable, and to save the volatile and soluble products which result from them.

6. The liquid manure should be collected, either in the pit or hollow intended for the other manure, or in a separate pit prepared for the purpose. The latter is the better method. If a tight floor can be made in the stable, it should be sloped from the heads of the cattle, and a channel made, along which the urine can flow into the pit. If the floor is open, the pit should be directly beneath it, or the ground below should be sloped to conduct the liquid into the pit. In whatever way arranged, the pit should be tight in the bottom and sides, and should be filled with soil, or peaty swamp mud, to absorb the liquid. Gypsum may also be added with great benefit; and the urine pit may very well form a receptacle for door-cleanings, litter which may accumulate about the barn, and every other kind of vegetable or animal refuse. These additional matters may occasionally be protected, by adding a new layer of peat or soil to the top.

The pit for liquid manure should be roofed over. A method much followed in Britain and the continent of Europe, is to collect the urine in a tank, and add sulphuric acid to prevent waste of ammonia. When used, the liquid is diluted with water, and distributed to the crop by a watering cart. This is too expensive for most of our farmers; but when it can be followed, it will be found to give an astonishing stimulus to the crops, especially in the dry weather of spring. Gypsum may be put into the tank, instead of sulphuric acid.

An examination of the table on page 216 will show that the combustible part contains a large amount of ammoniacal matter, and the rest is principally the richest humus or vegetable mould; while the incombustible part contains all the ingredients in the ashes of cultivated plants, and these in a soluble state, ready to be absorbed by the soil and taken up by the roots. This table, in short, affords the most conclusive evidence of the immense loss sustained by the farmer who allows his stable manures to be weathered, and their soluble part washed away by the rains. No economy in other respects, and scarcely even the most costly additions of artificial manures, can compensate this waste.

This subject is, in all its details, deserving of the careful study of every practical farmer.

When the circumstances of the farmer are such that he cannot provide shelter for his manure heap and tankage for his liquid manure, he may minimize the waste by thoroughly underdraining his barn yard. The leachings of his manure heap will then filter through the earth instead of flowing away in open drains, and will leave behind, absorbed by the earth,

the chief part of their valuable materials, water, nearly pure, alone escaping by the drains. The top layer of the barn-yard soil then becomes very rich, and should be carted out with the manure and spread upon the land, its place being supplied by a new layer of loam, or of mixed loam and peat annually supplied.

### § 3. *Green Manuring*

A large amount of organic matter, in a state ready to undergo rapid decomposition, may be furnished to the soil by ploughing in a crop of succulent herbage, such as buckwheat or rye or clover, grown upon the land itself. This mode of treatment can, of course, add nothing to the inorganic wealth of the soil, but it does greatly increase its organic richness by the addition of a large amount of carbonaceous and some nitrogenous matter derived from the air, and it renders available much inert nitrogenous material, and much inorganic material locked up in insoluble forms. While the buried vegetation is undergoing decomposition it affords the most favourable conditions for the development of those lower forms of life on which nitrification depends; by which nitrogen in an assimilable form is abundantly provided for the vegetation that is to follow. Besides decomposition immediately generates various powerful acids, as the acetic, followed as the decomposition advances by such as the humic and the ulmic, and ending as the decomposition is completed in the production of large quantities of carbonic acid, all being in direct contact with the inorganic particles of the soil, acting powerfully upon them, and provoking in various ways many complex chemical changes which issue in

ministering abundant soluble inorganic food to the rootlets of the following crop. Besides the rotting vegetation ameliorates the physical as well as the chemical condition of the soil. It renders loose sands more coherent and more retentive of moisture and manures, and it helps to disintegrate cold and lumpy clays. Accordingly, green manuring has been resorted to in the reclamation both of hungry sands and of soggy clays. When green manuring is so practised as to involve the loss of the crop of one year, it is and must always be an exceptional method of treatment. Then in order that the farmer may lose nothing, the crop of the succeeding year must be so much more abundant than it would otherwise have been, as to pay by its excess the cost of working and seeding the land for the green crop, together with interest on that cost and on the value of the land for one year. Only in rare cases can the increase of crops do this.

#### *Exercises.*

169. The pasture on a certain field is worth \$1.00 per acre per month. The owner can pasture it six months, then plough it up in the fall, put in oats in the spring and harvest 40 bushels per acre, at a total cost for labour and seed of \$8.55 per acre. Or he can pasture it three months, put in a crop of buckwheat, plough it under and put in and harvest a crop of oats of 55 bushels per acre, at a cost of \$10.75 per acre. Which had he better do, if oats will bring 35c. a bushel, and which if he cannot get more than 34c. a bushel?

#### § 4. *Other Organic Manures.*

The remaining organic manures may be arranged under the following heads:

1. Those which, like peat, bog mud, leaves, spent bark, saw-dust, straw, etc., consist principally or exclusively of woody fibre. These substances decay but slowly in the soil, and do not yield large quantities of the more rare and valuable of the substances required by cultivated plants. They are useful, however, in two points of view. They renew the supply of vegetable matter in the soil, and thereby ameliorate its texture ; and they afford, by their decay, substances useful in enabling plants to build up the tissues of their stems and leaves. They are also admirable absorbents for the richer parts of putrescent manures ; and by mixture with these substances, they are themselves more rapidly decomposed. Their use, therefore, is, as already indicated, to fill the urine pit, to form the basis of the dung-hill and the cover of composts and to serve as litter in the stable and cattle yard. They may also be used in top-dressing grass,—which they not only nourish, but protect from the frosts of winter.

2. A second class consists of the rapidly decomposing remains of animals and plants,—as dead animals, blood, night-soil, fish-offal, parings of hides, green succulent weeds, sea weeds, etc. The animal manures of this class, are of great value, being almost entirely composed of the materials which are most wanted for the production of the most nutritious parts of vegetables. The vegetable manures of this class, though less valuable, afford, in addition to their woody fibre, much alkaline matter and some nitrogen ; and some of them contain animal substances which add greatly to their value. Such manures should not be left exposed, nor should they, except in case of necessity, be applied in a fresh state to the land ; as in



their raw state, a slight excess of them often exerts a poisonous influence, and much of their richness is also apt to be wasted. They should be mixed with earth or peat, in the proportion, in the case of the richer kinds, of three to one, and well covered with a coating of earth. The whole mass will thus become a rich and valuable manure. In many places, there is sufficient fish-offal, if treated in this way, to fertilize large tracts of barren land ; whereas it is now totally wasted, or spread on grass land, to taint the air with odours which, if retained under ground, would furnish the elements of life and vigour to the crops. The same remark applies to dead animals, and all the putrescent refuse which is apt to accumulate about yards and outhouses. Exposed on the surface, these things are pestilential nuisances ; buried in the compost heap, they are the materials of subsistence and wealth.

As *Sea weed* is a very important manure, and is extensively applied in many parts of the sea coast, a few additional remarks may be made, respecting its composition and uses. The ashes of sea weed have been found to contain :

Soda and potash.....	15 to 40 per cent.
Lime .....	3 " 21 "
Magnesia .....	7 " 15 "
Common salt .....	3 " 35 "
Calcium phosphate.....	3 " 10 "
Sulphuric acid.....	14 " 31 "
Silica .....	1 " 11 "

These are all important substances, and, in addition to the nitrogen contained in the organic part of the weed, must exercise an important influence. Sea weed, however, is but a temporary manure, as it decays very rapidly ; and it is extremely unwise to place the



whole dependence on it, to the exclusion of other manures, especially of the stable manure. The farmer should save his stable manure, and consider the sea weed an additional, or supplementary aid. In this way, there will be no danger of his having to complain that, notwithstanding constant applications of sea manure, his land is becoming poor. He must also remember, that sea weed does not contain all the materials of land plants, in due proportion; and that, therefore, it cannot supersede the necessity of other fertilizers. With respect to composting sea weeds, some good farmers on the sea coast compost carefully all the weed obtained in autumn, and apply, in the recent state, that procured in spring. It has also been successfully applied as an autumn dressing to grass. This is certainly better than the practice, which I have observed in some places, of top-dressing grass with the stable manure, and applying nothing in the drills with green crops but sea weed.

Land weeds form a somewhat useful kind of manure, as they are often rich in alkalies, and other constituents of crops. Rank road-side weeds are especially valuable; and their removal prevents the dissemination of their seed, and improves the appearance of the country.

3. A third class is formed of those manures of animal and vegetable origin which, though highly fertilizing, are not liable to rapid decay; and are, therefore, permanent in their effects, and may be kept for application in a dry state. Such are bones, hair, hoofs, hen manure, guano, wood ashes, and soot.

*Bones* are of great value, as they afford that rare and important substance, phosphate of lime, along with a rich animal matter; ground bones, "bone dust,"

are now an important article of traffic as manure, and are of great value,—as five bushels are considered to be sufficient manure for an acre of turnips, especially if mixed with a little wood ashes. Every farmer should collect and apply bones. They are very valuable, even after being burned or boiled with potash for soap, because, they still contain their phosphate of lime, though deprived of their animal matter. Where means for grinding bones cannot be obtained, they may be broken into small pieces by the hammer; they may then be mixed with an equal quantity of earth or ashes, moistened, and left to heat before being put into the drills. For practical illustrations of the value of bones, I may refer to Jackson's Agriculture. Among other instances, he mentions, that a dressing of 600 bushels on 24 acres of poor pasture had so improved the grass, as to double the yield of butter; and this effect endured for many years. In this case the pasture had been laid down for ten years, and, no doubt, much of its natural phosphate of lime had been exhausted, to form a constituent in the milk and bones of the cattle that had fed on it.

*Hair* and *Hoofs* are rich manures, though they decay slowly. Such substances, from tanneries, etc., should be saved, and applied to the land. At the rate of twenty or thirty bushels per acre, they produce marked effects.

*Guano* is a manure produced by the slow decay of the droppings of sea birds, in dry climates, and is chiefly obtained from islands on the coast of Peru. Peruvian guano formerly contained from fifty-six to sixty-six per cent. of ammoniacal salts and organic matter, and from 16 to 23 per cent. of phosphates.

Now, however, the rich deposits formerly worked being exhausted, inferior grades containing only about 8 per cent. nitrogen, 12.15 per cent. phosphoric acid, and 2.3 per cent. potash are alone attainable; even these are probably sophisticated. Very excellent artificial guano is now made in Newfoundland and in Maine from fish refuse, by boiling, pressing, and drying, and then coarsely grinding or crushing. When pure and genuine, these artificial guanos are among the richest of portable manures.

*Wood ashes* may be applied with any crop; but not in very large quantity, as they not only act powerfully as a manure, but exert a caustic or decomposing influence on organic manures, and on the roots of plants. Fifty bushels per acre, is the largest quantity that can be safely applied to heavy soils, rich in vegetable matter. Lighter soils should have a much smaller quantity; and on light soils even a few bushels will produce marked benefits. *Kelp*—or the ashes of sea weed—and peat ashes, are similar in their effects to wood ashes, but less powerful.

The great value of wood ashes may be estimated from the remarkable effects produced by them in new land, where the ashes of forests, the growth of centuries, are at once applied to the surface. The substances which they afford, may be learned from the following analysis of the ashes of beech wood:

Potash .....	15.83 per cent.
Soda .....	9.79 "
Common Salt.....	0.23 "
Lime .....	62.37 "
Gypsum.....	2.31 "
Magnesia.....	11.29 "
Oxide of Iron.....	0.79 "
Phosphoric Acid .....	3.07 "
Silica.....	1.32 "

These are the principal substances on which new land depends for its fertility; and the loss of which, either by wasteful cultivation or by repeated burnings followed by rain, causes its exhaustion. These ashes produce the best effects when a considerable proportion of the vegetable matter of the soil remains unconsumed; both because this vegetable matter serves to retain the ashes, and because it prevents their caustic effects from being too strongly felt. On the other hand, when the vegetable matter is entirely consumed, the ashes are rapidly wasted, and the crops suffer from deficiency of organic manure. Leached ashes, having lost their potash and soda, are of less value than recent ashes, but are still of great utility.

*Peat ashes*, though less valuable than those of wood, have been extensively used as manure, especially in Holland, and in applying peaty matter as manure, the value of its inorganic part should be taken into account. Hunt gives the following analysis of the ashes of peat from St. Dominique, Quebec:

"A watery solution of the ash contained chlorine and sulphuric acid combined with potash and soda, and a large amount of sulphate of lime. The whole of the alkaline salts were dissolved by the water. The ash was strongly alkaline in its reactions, and contained, as might be expected, the magnesia and some of the lime in a free state." 100 parts of it gave me:

Lime .....	47.040
Magnesia.....	3.150
Ferric Oxide.....	4.380
Alumina .....	2.440
Oxide of Manganese.....	.040
Potash .....	.330
Soda .....	.254

Chlorine.....	.241
Sulphuric Acid .....	9.173
Phosphoric Acid .....	.932
Carbon dioxide. ....	23.060
Silica .....	4.920
Sand (mechanically present).....	4.040
	<hr/>
	100.000

Such a substance must act powerfully on any soil in want of sulphates, phosphates, lime, or silica, and it is probable that the ashes of peat from most of our bogs would be found to possess similar properties.

*Soot* contains ammonia, and sulphates, carbonates, hydrochlorates and phosphates of lime, potash, soda, magnesia, etc. It is, therefore, a very powerful manure, and, like guano, need be applied but in small quantity.

To this class of manures, I may add the offal of codfish, which may be obtained in large quantity in some of the fishing districts. If dried, and packed in old barrels or crates, it might be preserved and conveyed into the interior districts. As it consists largely of phosphate of lime and rich animal matter, it is nearly as valuable as guano, and would be well worth 5s. or 6s. per cwt. It should be cut up, or crushed, and mixed with soil to ferment before being applied. It should be used in drills with potatoes or turnips.

It may also be of service to add here, that night-soil, urine, and other offensive animal substances, may be converted into a manure of great power, and quite inoffensive, by mixing them with powdered charcoal, or charcoal and gypsum, or even with dry earth. They may then be sown like guano, and will produce similar effects. Artificial manures, called *poudrettes*,

are often prepared in this way. Farmers would find it profitable to have constantly at hand a quantity of charcoal and powdered gypsum for such purposes.

The value of the manures above enumerated depends almost wholly on the nitrogen, phosphoric acid and potash which they contain, the availability of these substances being considered. For immediate effect nitrogen in bone meal is worth four times as much as the same amount of nitrogen in ground leather scrap. In guano, bone meal and the more readily putrescible animal matters, nitrogen may be estimated as worth 15c. a pound. Phosphoric acid occurs in manures combined with lime in the three forms mentioned on page 101. The ter-phosphate is the form in which it occurs in bones, and in apatite; the diphosphate, or, as it is often called in connection with manures, reverted phosphate, is slowly produced when calcium monophosphate and calcium ter-phosphate are mixed. Monophosphate or superphosphate is the form in which it should be found in artificial manures.

Pure calcium ter-phosphate is soluble only to a very small extent in water—about one part in 90,000—but to twice as large an amount in water saturated with carbon dioxide. The diphosphate is more soluble, one part dissolving in about 18,000 parts of pure water, and being four times as soluble in water saturated with carbon dioxide. The monophosphate, or superphosphate, is readily soluble in water. Phosphoric acid in the state of ter-phosphate may be valued in manure at 5c. a pound, in the state of diphosphate at 6c. a pound, and in the state of superphosphate at 10c. a pound. In insoluble phosphates generally phosphoric acid may be valued as in the

ter-phosphate of lime. Potash may be valued at 5c. a pound.

A useful mode of estimating the value of fertilizers is to reduce the above prices to a price for each one per cent. in a ton of manure. One per cent. of a ton is of course 20 lbs. Therefore twenty times the value of a pound of any fertilizer is the value of one per cent. of it in a ton of manure. Estimated thus one per cent. of nitrogen per ton is worth about \$3.00, of phosphoric acid in superphosphate \$2.00, in reverted phosphate \$1.20, of ter-phosphate and insoluble phosphates in general \$1.00, and of potash \$1.00.

*Examples.*

170. What, by the above scale of values, is the worth of one ton of barn-yard manure, which contains 76% of nitrogen, 14 of soluble and 18 of insoluble phosphoric acid and 96% of potash?

171. What is the worth of 100 gallons of liquid stable manure weighing 11 lbs. per gallon and containing 8% of nitrogen, 3% potash and an inappreciable amount of phosphoric acid?

172. What is the worth of bone dust per ton, the guaranteed analysis of which give 15% of nitrogen and 20% of insoluble phosphoric acid?

173. What is the worth per ton of a sample of bone dust containing 27% of insoluble phosphoric acid and 5% of nitrogen?

174. Calculate the value per ton of an artificial manure containing 3 per cent. nitrogen, 5% soluble phosphoric acid, 5% reverted phosphoric acid and 2½% potash?

175. If all the phosphoric acid in the foregoing



sample had been soluble, what would the value have been per ton?

176. Another brand of artificial manure contains 2% nitrogen, 4% soluble and 2½% reverted phosphoric acid, and 2½% potash, what is it worth per ton?

177. What is the worth per ton of a fertilizer containing 3% nitrogen, 8% soluble phosphoric acid, 2% reverted phosphoric acid, 2% insoluble phosphoric acid and 2% potash?

178. A sample of Saldanha Bay guano contained 9% nitrogen, 9·2% insoluble phosphoric acid and 1·3% potash; what was it worth per ton?

179. Formerly Chincha Island guano gave 13% nitrogen, 12% phosphoric acid (insoluble) and 2% potash. What would its worth be per ton if it could be now procured?

180. A sample of Peruvian guano sold at \$70.00 per ton, showing 8¾% nitrogen, 14% phosphoric acid and 2% potash. Was this price excessive? What should it have sold for?

181. When the above guano was sold chemists valued its nitrogen at 30c a pound, its phosphoric acid at 6c a pound, and its potash at 4½c a pound. What was the ton of guano worth at these prices?

182. What is the value of 1 ton of wood ashes as described on page 229?

183. What is the value of 1 ton of peat ashes as described on page 230, if its potash and phosphoric acid alone be considered?

184. What is the value of 1 ton of the ashes of sea-weed containing 15% of potash and 5% insoluble phosphoric acid?

185. What is the value as manure of one bushel of wheat? of barley? of oats? of rye? of maize? of

peas? of potatoes? of carrots? of mangolds? of rutabagas?

N.B.—Consult tables on page 141, and reckon the phosphoric acid as soluble.

186. What is the value for manure of one ton of wheat straw? barley straw? oat straw? rye straw? corn stalks? pea straw? timothy hay? red clover hay? green maize? green rye? green oats?

### § 5. *Mineral or Inorganic Manures.*

After what has been already said, it is scarcely necessary to mention here that manures of this kind may be as truly the food of plants as substances that have already actually formed parts of vegetable substances. Any of the substances mentioned above as necessary ingredients in fertile soils, or in the ashes of crops, may produce valuable effects, if they can be procured from the rocks of the earth, or any other source, and applied to the land. The beneficial influence of these substances may be summed up under the following heads:—

1. They may supply original chemical or mechanical wants in the soil. They may furnish substances required by some or all crops, and previously deficient; and thus not only directly promote the growth of crops, but enable them to avail themselves of other materials which, though abundant, they could not use, from want of that which was deficient. For instance, if clover contains in its ashes 28 per cent. of lime, and if the soil contains so little that, in the course of the season, the plants can get only half the quantity they require, they will take just so much less of everything else, and produce little more than half a crop. Hence the addition of lime to such a

soil will enable clover to take a great deal more of other kinds of food, and the effect on the crop will be very marked. On the other hand, if the soil contains a sufficiency of lime, its addition as a manure may produce no appreciable effect. We learn from this, the nature, in part at least, of what is called the stimulating and exhausting effect of mineral manures; and also the reason of their frequent failure. A farmer who finds by experience that some mineral ingredient, as lime, gypsum, etc., produces marked benefit, continues to apply it, and neglects other manures, until at last it produces no effect, and he finds that his land is completely run out. He now says that, after all, his supposed fertilizer was only a "stimulant," and condemns it; whereas the error is in his own ignorance of the fact that, though necessary to fertility, it only rendered more necessary a sufficient quantity of the other kinds of food required. It is just as if a farmer were to find the appetite and flesh of his cattle falling off, and were to add some salt to their food; and finding this to remedy the evil, were to withhold all other nourishment and attempt to feed them on salt alone. Again, a farmer, anxious to improve, learns that great benefits have resulted from some mineral manure. He at once applies it on a large scale, and is surprised to find that it does no good whatever. The reason probably is, that his land has already enough of it, while that to which it has been successfully applied had not. He should have ascertained by experiment on a small scale, or by an analysis made by a competent person, the actual state of his land in reference to this particular substance; and then he might have proceeded with certainty. These errors, arising from

imperfect knowledge, work incalculable mischief to the cause of agricultural improvement. The true course with respect to mineral manures, is to test the land as to its wants; and then to supply what it needs, without neglecting other ordinary manures.

2. Mineral manures may produce chemical changes in the soil, which may preserve or render useful other substances previously present, or may decompose poisonous ingredients. I have already had occasion to notice the effect of gypsum in saving ammonia, and that of lime in decomposing sulphate of iron, and neutralizing vegetable acids. Lime also exerts a powerful influence in decomposing inert vegetable matter, and even small stones and gravel which may contain matter useful to the soil. This is what we may call, if such a term can be properly used, the true *stimulating* effect of mineral manures.

After these general remarks, it will not be necessary to dwell at any great length on the separate mineral manures. I shall therefore briefly indicate their uses, sources, and the modes in which they may be best applied.

*Lime* is an important ingredient in the ashes of most plants. It exists most abundantly in the state of carbonate, either in the form of limestone or in the substances called marls, and which consist of mixtures of carbonate of lime with sand and various earthy matters. Lime, in both of these states, is abundant in most parts of this country; though it may be observed, that those tracts whose soils are most deficient in lime, are precisely those in which beds of limestone and marl are most rare.

Marl is found in large beds, especially in the gypsiferous districts of New Brunswick and Nova

Scotia. These large marl beds are usually of grey or brown colors, and often contain small irregular veins of gypsum. The decaying surface of many beds of limestone also affords a substance which may be classed with the marls. In some low grounds which have formerly been ponds or lakes there are beds of clay mixed with fresh-water shells; and in creeks and harbors there are mussel and oyster beds which afford a similar substance, containing also much valuable animal matter; these are known as shell marls. They exist in very many parts of Canada, numerous localities being noticed in the Reports of the Geological Survey. On some parts of the coast also large quantities of sea-shells, mixed with sand, may be collected on the beach, and may be called shell-marl, as they are quite analogous in composition and effects. All these substances may be applied in large quantity with benefit to most soils; more especially as in this mild state the lime exercises no destructive influence on the organic matter of the soil. The earthy marls may be used for mixing with composts, or laid on as a top-dressing. The shell marls, which contain much animal matter, should be covered and composted with earth, and applied with root or grain crops. Marls may be distinguished from common clays and sands by a very simple test. Put a little of the substance into a wine glass or tumbler, and add a little water, sufficient to make it into a thin paste. Then pour in a few drops of hydrochloric acid, and observe if any effervescence or boiling up occurs. If a marl, it will boil up with considerable force; if not a marl, with less force; and if not a marl at all, there will be no effervescence or scarcely any. Limestone may be distinguished from other rocks in the same way.

Limestone ordinarily requires to be burned in order to be rendered fit for application to land. Burning deprives it of its carbon dioxide, and brings it into the state of quick or caustic lime, calcium oxide, or after it is slaked with water, into that of calcium hydroxide, or lime combined with water. In these forms, it is most suitable for mixing with crude vegetable matters, as peat, which it is desirable speedily to decompose, and also for application to some bogs; but in these forms its application in large quantity to very light soils is most dangerous. It remains, however, but a short time in the state of caustic lime, for whether in the soil or on the surface, it gradually absorbs carbon dioxide from the air and from the organic matters with which it comes into contact, and passes back into the state of carbonate, the same state in which it was before being burned; so that ultimately the principal result of the burning is that of reducing the lime to fine powder, which can be uniformly diffused throughout the soil. This change does not, however, fully take place for a very long time. It is principally this strong affinity for carbon dioxide which causes lime to hasten the decomposition of organic matters, by creating a powerful demand for the carbon dioxide which is one of the principal products of their decay; and as this carbon dioxide is a useful part of the food of plants, in poor soils an excess of caustic lime not only wastes the organic matter, but takes away the little vegetable food which it is producing. In like manner, caustic lime is altogether unsuitable for mixing with rich animal manures, as the rapid decay which it induces sets free and wastes all the ammonia which they contain. This is well shown by mixing a little quick lime with



guano. The intense odor of ammonia given off indicates at once the destructive action of the lime, and the large quantity of ammonia in the manure. If a rod dipped in hydrochloric acid be held over the mixture, the ammonia becomes visible as a white cloud of hydrochlorate of ammonia.\*

As a decomposing agent, then, quick lime is most rapid and efficient, but mild lime acts in the same way, though more slowly. To the action of both kinds, however, the presence of air is necessary. The oxygen of the air is required in the decay of all kinds of organic matter, and since lime acts in promoting decay, its influence will in a great measure depend on the greater or less readiness with which air can penetrate to the vegetable matter of the soil. For this reason, when lime is mixed with organic matter in close vessels or in very stiff impermeable clays, it tends to harden and preserve, rather than to decompose it; in such soils, therefore, draining and loosening the ground are necessary in order that lime may exert its proper influence.

The decomposing power of lime, explains its beneficial influence on peat-bogs, and other soils surcharged with moisture and undecayed woody matter. In such places the vegetable matter, long soaked in stagnant water, produces in the slow changes which it undergoes, the humic, ulmic and other organic acids, which communicate what is very properly named sourness to the soil, and render it fit only for the growth of coarse grasses, ferns, moss and similar plants. But when lime is applied it enters into combination with these acids, and at the same time causes

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\* The same test indicates the escape of ammonia from rich manures when decaying too rapidly.



the inert woody matter to decay and fill the soil with products valuable as food for plants. It is to this cause that we must also in great part ascribe the beneficial change which lime effects in pasture lands overgrown with coarse grasses, or more useless herbage, causing this rank vegetation to give place to tender grasses and clover. In all these cases the lime is merely the means of bringing into a useful form a quantity of matter previously existing in the soil in an inactive or positively injurious state. In the case of swampy land, however, we must not forget that lime will prove only a partial and temporary remedy, unless it be assisted by draining.

The facts already stated will enable us to understand the utility of composting peat, black swamp mud, and similar substances, with lime. By the decomposition which they are thus caused to undergo, they are converted into valuable manures.

Since the benefit of lime arises in great part from its power of bringing into use the stores of food already present in the soil, it is plain that its effects must be greatest in soils which contain abundance of vegetable matter, and also that its tendency is to *exhaust* this matter more rapidly than if lime were not used. Heavy liming, therefore, when not accompanied with other manures, must, at each successive application, produce less effect, and end in causing comparative barrenness. From observing this injurious effect of the misapplication of lime has arisen the English proverb that, "Lime makes rich fathers, but poor sons." The Germans have a better proverb, to the effect that heavy liming and heavy manuring must go together.

These considerations also show how lime may

"burn up" and impoverish some light soils, by wasting with unnecessary rapidity their already small stock of vegetable mould. When applied to such soils, lime should be either in the form of clay marl, or of composts made of peat, sods, ditch cleanings or similar matters, which will furnish it with materials to act upon, without exhausting the soil.

Lime also exerts an important *influence on the inorganic materials of soils*. It has been already mentioned that the soluble salts of iron present in some boggy lands, and injurious to vegetation, are decomposed by lime, owing to its superior affinity for the acids which they contain. Another change of the mineral matter of the soil, effected by lime, depends on its affinity for silica, which is sufficiently powerful to enable it gradually to decompose fragments of granite, trap, and other rocks consisting of silicates, combining with their silica and setting free their potash, soda, etc., in forms very useful to crops. Beside these, there can be little doubt that lime aids in effecting many other changes among the mineral ingredients of soils, tending in many cases to make their constituent parts more available for the nourishment of vegetation.

*Duration of the effects of Lime.*—When lime, in the quick state, is placed in the soil, it acts energetically from the moment of its application until it is reduced to a state of partial mildness, when its influence is exerted more slowly. This slower action, however, continues with unabated, or even increasing vigor, for two or three years; and although it may then diminish, the influence of a heavy liming may be felt even thirty years after its application. The decrease of the influence of lime may be accounted

for in different ways. It is usually applied only to the soil near the surface, and has a tendency to sink downwards into the subsoil. In light soils, this may be caused by the fineness of its particles, which causes them to be washed down between the coarser grains of the soil. In rich and close soils, however, it is very probably due to the earth-worms, those industrious agriculturists which are constantly employed in carrying to the surface the finer parts of the soil, on which they feed, a process which must result in the burying of every substance which they are not inclined to devour. Lime is also dissolved by water impregnated with carbon dioxide, and is rendered soluble by combining with various acids present in the soil, and in these states much of it is absorbed by the roots of crops, and much washed away from the ground by rains. Another mode in which the influence of lime may gradually become insensible, is by its combining with silica, and forming an insoluble compound, possessing none of the active properties of lime.

*Quantity of Lime which should be applied.*—When land is originally destitute of lime, a large quantity may be mixed with the soil, with beneficial results. This will be evident when we consider that in order to give one per cent. of lime to a soil six inches deep, we must apply above three hundred bushels of lime to an acre. If, therefore, the lime be well mixed with the soil, a large quantity may be used without producing any very great change. The quantity of lime which should be applied, depends, however, in a very great degree, on the nature of the soil. Clay ground and swampy land are often benefited by very large doses; as much as seven hundred bushels on the acre have been added to land of this description, without

producing any bad effects. Light and sandy soils, on the other hand, may be injured by a dose which would be much too small for clay land. To these circumstances, therefore, attention must be paid, as well as to the proportion of lime naturally present.

Since lime gradually disappears from the soil, it is necessary that the supply should be renewed at intervals; and it is plain that a more uniform effect will be secured by adding small quantities frequently, than by using large doses at long intervals. The practice of farmers has, however, varied very much in this respect, according to their various circumstances. In some parts of Scotland, forty-six bushels of quick lime per acre, are applied every five years; in others, two hundred to three hundred bushels are used once in nineteen or twenty years. In Flanders, ten to twelve bushels are applied once in three years, or forty to fifty bushels once in twelve years. In many parts of England, lime is applied once in every rotation of three or four years. The different length of the intervals in these cases does not appear to be of very great importance, and may be varied by every farmer to suit his own convenience. Small applications at short intervals are, however, evidently safer and more efficacious than large doses seldom repeated.

Enough has now been stated to show the uses of lime and their reasons, and to prevent us from being deceived by the hasty assertions, respecting its utility and inutility, frequently made by persons whose views on the subject are only partial. The results of an enlightened view of what is known with respect to this valuable manure, may be summed up as follows:—

1st. Lime has *ultimately* the same effects whether

it be applied in the quick, air-slacked, or mild state ; it should be well mixed with the soil, but kept as near the surface as possible ; and it should be renewed at intervals of a few years.

2dly. The mechanical effects of lime in opening and loosening the soil, are always beneficial on heavy soils, except where these are very wet and undrained ; and, on the other hand, they are sometimes injurious to very light and dry ground.

3dly. The chemical effects of lime, when properly applied, are—affording a necessary part of the food of crops ; bringing into activity the inert vegetable matter of the soil, and decomposing some mineral compounds which are injurious to vegetation, and others whose constituents are of great utility when set free by its action. By these means it tends to discourage the growth of moss and many other useless plants in pastures and hay fields, and encourage that of valuable grasses and clover ; to increase the quantity and improve the quality of grain and green crops ; and to augment the benefit of vegetable manures.

4thly. When applied to land already abounding in lime, or very deficient in vegetable mould, it may produce no benefit ; and applied in too large quantity, or when not accompanied with sufficient supplies of vegetable manures, it may be highly injurious by exhausting and impoverishing the soil.

5thly. Just as some cultivated plants cannot thrive without a good proportion of lime, there are some wild plants native to poor non-calcareous soils which are destroyed by liming. Hence liming and sowing with grass are sometimes sufficient to replace the most useless plants with nutritious grasses.

Some varieties of limestone contain a large

proportion of magnesia, which, when added to the soil in quantity, produces an injurious effect. These limestones are generally known as magnesian limestones or dolomites.

2. *Gypsum*.—The uses of this substance have already been often referred to. 1. Gypsum supplies sulphate of lime to crops, and, in general, is the cheapest form in which the sulphuric acid—shown by analysis to be present in the ashes of cultivated plants—may be obtained by the farmer. For instance, 1000 lbs. of dry clover and timothy hay are said by some analysts to contain from  $3\frac{1}{2}$  to  $4\frac{1}{2}$  lbs. of sulphuric acid; or we may estimate the quantity of sulphate of lime, or gypsum, required by a moderate hay crop, at 20 to 30 lbs. per acre. When gypsum is naturally deficient in the soil, great results may be expected from its application, especially in the growth of those crops which contain large quantities of this substance. 2. Gypsum possesses great value from its property of converting ammonium carbonate—one of the most volatile products of the decay of animal substances—into the ammonium sulphate, according to the equation  $\text{CaSO}_4 + 2 (\text{NH}_4) \text{CO}_3 = 2 (\text{NH}_4) \text{SO}_4 + \text{CaCO}_3$ . The great advantage is that the ammonium sulphate, not being volatile, is not lost in the air.

The influence of gypsum is thus very different from that of lime or marl. It does not tend either to waste or render available the vegetable matter of the soil; nor does it remove the sourness and coldness of heavy soils. On the contrary, it rather tends to give body to light soils. As already stated there is reason to believe that on many exhausted soils in the interior of Canada gypsum will be found to be of great



value, the soils being deficient in sulphates. In the vicinity of the sea, experience has shown that gypsum is less useful than farther inland; apparently because the sea spray carried by the wind supplies to the soil a small quantity of sulphate of soda, which serves instead of gypsum. Again, some soils, especially those in the vicinity of the gypsum beds, are already well supplied with this substance; and some soils in slaty districts, though deficient in gypsum, receive supplies of sulphuric acid from the sulphuret of iron contained in the slate. Coal ashes, peat ashes and sea weeds where applied, also furnish small quantities of gypsum. The second use of gypsum, however, to which I have referred, is one that applies to all soils and situations. In the stable, the urine-pit, the dung-hill, and the compost-heap, gypsum is always useful; and when scattered on the potato or turnip drills, or the hills of corn, it will always stand sentinel over the rich manures beneath, and preserve their ammonia in the soil. This is especially true in the case of light sandy soils. For such uses every good farmer should always have at hand a supply of powdered gypsum.

The cheapest way of rendering gypsum fit for use is to break it into pieces, and burn it after the manner of lime—though it does not require so great heat as limestone. Burning only drives off its water, without producing any other chemical change. After burning, it may be easily crushed into powder; but must be kept dry, otherwise it will set into a solid mass. The fine rubbish of gypsum quarries, and also the marly beds in their vicinity, may often afford a very cheap supply of gypsum. Crushed gypsum is offered for sale under the name of land plaster. Gypsum constitutes a necessary part of commercial



superphosphates; each one per cent. of soluble or reverted phosphoric acid is accompanied by two per cent. of gypsum.

It may seem contrary to the above remarks in reference to gypsum, that in the United States, where plaster has been largely applied, it has been accused of running out, or impoverishing the land. This is well explained by Norton on a principle already referred to: "In many cases a few bushels per acre bring up land from poverty to a very good bearing condition; complaints are, however, made that after a time it injures the land, in place of benefiting it. This, in almost all instances, results from using it alone, without applying other manures at the same time. The explanation is of the same general nature as that given under lime. The farmer has taken away a variety of substances, and has only added gypsum. If the land is entirely exhausted at last under such treatment, it is obviously not the fault of the gypsum. There are many large districts where it produces no effect; but it may always be considered certain that where gypsum or lime does no good, there is already, in one form or another, a supply naturally in the soil; or, as has been previously explained under lime, there is some physical or chemical defect which prevents its action."

3. *Potash and Soda*.—The sources of these in the ashes of plants have been already referred to. Sea salt contains soda in combination with chlorine; and it may be made more useful to plants by mixing it with quick lime. It will generally be found very useful to slack lime intended for land with sea water; and no better use can be made of refuse salt or brine, than to pour it upon quicklime or mix it with a

lime compost. Granite contains a large proportion of potash; and though a granite compost may seem a strange thing, crushed granite has actually in England been mixed in heaps with quick lime, for the purpose of setting free its potash. This is the only recipe that I know, for meeting the wishes of a gentleman in one of our more rocky districts, who once said to me, "There would be some use in your agricultural chemistry, if you could dissolve these granite rocks for us." Farmers who can obtain the smaller dust and fragments of granite quarries and masons' sheds, where granite is worked, and who are not located on granitic soils, will find it pay to cart such material and mix it with the lime they intend to apply to their land, covering the whole with a thick coating of clay and letting it stand for a few months. The effect will be greater if the granite be previously burned like the lime. The softer varieties of trap rock, which also contain much alkaline matter, may be treated in the same way; or may be usefully applied to poor soils without any preparation.

The great source of potash at present is the Stassfurt mine in Germany, which yields, besides rock salt, almost inexhaustible quantities of a double chloride of potassium and magnesium, with potassium, sodium and magnesium sulphates. From these minerals potassium chloride, (called in the trade muriate of potash), and potassium sulphate, both mixed with various impurities, are prepared and largely used in agriculture, more particularly as intermixtures with other substances in the manufacture of artificial manures. These preparations are sold at prices such that their potash may be valued at 5c. a pound.

4. *Phosphate of Lime*.—Small quantities of this

highly valuable substance are contained in most limestones, and conduce greatly to the benefits resulting from liming. Those varieties of lime which contain large numbers of impressions of shells and scales of fishes, are usually most valuable in this way. Some thin and impure limestones of little use for ordinary purposes, are rich in phosphates. This is especially the case with beds containing many of the fossil shells called *Lingulæ*, and with some beds of the coal districts containing scales of fishes. In many parts of Canada there are extensive beds of apatite, a crystalline phosphate of lime, which are quarried for exportation. This mineral is crushed and prepared with sulphuric acid, which renders it soluble as superphosphate of lime. When manufactured in this way, it is invaluable on the worn out farms of the older districts of this country. Superphosphate of lime may be purchased at from \$14 to \$24 a ton, according to the percentage of soluble phosphate it contains.

Bone-dust, guano, and the liquid manures of stables, are important sources of this substance to the farmer, and have been noticed under the head of organic manures.

*Coal Ashes.*—The ashes of coal consist principally of silica and alumina, which constitute over 86 per cent. of their weight. These substances are in a fine state of division, and give the ashes a great power of absorbing liquids and gases. Coal ashes also usually contain oxide of iron, carbonate of lime, sulphate of lime, magnesia, and minute quantities of silicates of potash and lime, and of phosphate of lime.

Though the ashes of different kinds of coal differ somewhat in composition and absorbent power, and are much inferior as manure to wood ashes, yet they

are always of some service, more especially when employed to absorb and retain liquid manures and the soluble and volatile parts of organic substances.

## CHAPTER XV.

### CROPS.

Under this head we shall consider the bearing of the principles previously stated, on the plants ordinarily cultivated in British America, and shall notice the peculiar habitudes of these plants and their diseases and enemies.

#### § 1. *Wheat.*

— All the kinds cultivated in this country belong to one species, but of this there are two leading varieties, —the spring and winter wheat,—and under each, many subordinate varieties, produced by culture and selection.

Wheat, when permitted, sends its roots deeply into the ground, and therefore prefers a deep soil, or one that has been deepened by subsoiling and under-draining. It requires to have in the soil a supply of both mineral and organic food in a well elaborated state. Hence it will neither thrive in a poor soil, nor in one the riches of which consist of vegetable matter in a crude or undecomposed state. It also very readily permits weeds or grasses to grow beneath its shelter. For these reasons, newly burned land, land that has been fallowed and manured with composted manure, or land clean and well manured, that has just carried a soiling crop, or clover or peas, is most suitable for winter wheat. Spring wheat should follow a hoed crop. On lea land it is very subject to rust, and also to the attacks of the Hessian fly, whose

larvæ are generally present in the grass, and destroy the wheat which takes its place. The place of wheat in the rotation of a scientific farmer must, therefore, be like that assigned to it in the ordinary Scottish four-course rotation, viz., after a green crop and before grass, which is sowed with the wheat.

The organic part of the grain of wheat consists principally of gluten, albumen, starch, gum, sugar, oily matter, and the woody matter of the husk. Of these ingredients the most important in reference to human food are the gluten and albumen, which are also the substances whose elements are least easily obtained from poor soils. They are obtained from the richer kinds of manures; and their nitrogen,—the most difficult of their elements to procure, chiefly from the ammonia and nitric acid afforded by these manures aided by the atmospheric supply. It is also worthy of remark, that the percentage of gluten varies according to the amount of such rich materials in the soil. Hence the wheat of well manured land is not only more abundant, but yields bushel for bushel more flour—and more nutritious flour than that of poor land. The rich and well tilled soils of this country produce wheat equal to that of any country in the world. The poor and worn out lands furnish inferior grain, milling badly, and yielding an inferior flour deficient in gluten.

The ash or earthy part of wheat is also of some importance, especially as for this the plant is entirely dependent on the soil; and though this part of the plant is comparatively small in quantity, yet its due supply is absolutely necessary to healthy growth.

More than one-half of the ash of the straw of wheat consists of silica, an element sufficiently abund-

ant in most soils ; but it is to be observed that this element can be obtained only by the aid of potash or soda, which must therefore be present in the soil. Potash and soda are also required independently of the conveyance of silica. The ashes of 1000 lbs. of the grain of wheat contain 6 or 7 lbs. of potash and soda ; the straw contains a much smaller proportion. Wheat also contains in its ash, lime, gypsum, magnesia and common salt, but in small quantity. The ingredient of the ash of wheat, which of all others is the most important, is bone earth or phosphate of lime, of which about 100 lbs. are taken by a good crop of wheat from an acre of ground. This may appear to be a small quantity, but it must be borne in mind that this substance is scarce even in fertile soils. It is chiefly the presence of alkalies and phosphates derived from the ashes of the woods that causes wheat to produce so abundantly in new land.

The facts respecting the composition of wheat stated above, indicate that manures containing nitrogen, phosphates and alkalies, are especially suitable to it. Such manures, in addition to the richer farm yard manures, are nitrate of soda, muriate of potash and superphosphate. Of these the first is always valuable, and the last is more important to spring than to winter wheat.

After peas, when the ground is clean, or after a hoed crop, the ground is sufficiently prepared for sowing wheat by the use of the cultivator, but after a soiling crop or clover, or if the ground be weedy, it will be necessary to plough the land. For winter wheat the ground should be ready for the seed during the first part of September ; not much earlier lest the



too abundant leafage be smothered under the snow, nor much later lest the growth before arrested by winter be insufficient to shelter the roots. From one bushel to two bushels of well ripened seed is sufficient for each acre, the larger amount is required in poor soils with spring wheat sown broadcast, the smaller in rich soils with winter wheat drilled in. With winter wheat timothy is sown and clover on the same crop in spring. With spring wheat both timothy and clover are sown. These grasses flourish under the shade of the wheat.

If winter wheat be partially thrown out by frosts, it is well to roll it in the spring; and, where labor is available, it is well to hoe and weed it at the same time. Generally, however, the crop grows without further care after the seeding until harvest.

Wheat should be harvested for the miller when the straw immediately beneath the ear begins to turn yellow; for the straw of wheat, if cut sufficiently early, and chopped with a straw cutter, is highly nutritive food for cattle and horses, and is much relished by them. In this country wheat is generally cut too late, and the grain is thick in the husk and inferior in flouring qualities, and the straw is comparatively worthless. By cutting immediately after the grain is filled, and before the straw is wholly dead, both would be much more valuable and nutritious.

Wheat, though the most important of grain crops, has, of late, acquired the character of being a precarious crop, especially in the older districts. It becomes therefore necessary to enquire into the diseases and blights to which it is liable. We may consider these in some detail, remarking in the first place that none

of them are peculiar to British America, all of them being more or less experienced in most or all the countries in which wheat is cultivated.

1. *Rust*.—A reddish or rusty substance attached to the straw and leaves of wheat in the end of summer or in autumn. When examined by the microscope, it is found to be a parasitic fungus or mould whose minute and invisible seeds or spores are wafted by the winds, or borne to the plant with the water it absorbs from the soil, and taking root in the cells and vessels of the stem and leaf, weaken or kill it by feeding on its juices.

Its attacks are favored by the following causes: *First*, damp and cold weather succeeding warmth, at the time when the straw is still soft and juicy; hence late grain is very liable to rust. *Secondly*, a deficiency of the outer silicious coat, which in the healthy state protects the surface of the straw, or an unnaturally soft and watery state of the plant. These unhealthy conditions may proceed either from poverty and want of alkalies in the soil, from the presence of too much crude vegetable matter, as sed or raw manure, or from a wet and undrained state of the land, which both causes the crop to be late and fills it with watery juices. *Thirdly*, it is highly probable that one inducing cause is the accumulation of sugar and albuminous matter in the straw, and the inability of the plant, owing to the want of phosphates, to turn this sugar and albumen into the starch and gluten of the seed. *Fourthly*, it is probable that when the grain of rusty wheat is sown, or when sound wheat is sown in ground in which wheat has rusted in previous years, the crop may be more easily affected by the disease, because the spores of the rust fungus may be attached to the seed or may be in the soil.

The best preventives of rust therefore are: *First*, healthy seed; *Secondly*, early sowing; *Thirdly*, draining; *Fourthly*, abstaining from sowing wheat in lea land; *Fifthly*, preparing the soil in such a manner that it shall be sufficiently rich, yet not filled with crude vegetable matter, paying attention to the supply of alkalies and phosphates.

2. *Mildew*.—This term is often used in this country as synonymous with rust; but properly speaking, mildew is the effect of the growth of other fungi, which are however not dissimilar in their habits from the rust fungi; though in this climate less destructive.

3. *Smut or Bunt*.—This also is a parasitic fungus, which grows *within* the grain, and converts its substance into a dark colored fetid mass of spores or mould balls, which under the microscope look like rough berries, and are filled with the minute dust-like spores of the smut. Its mode of propagation is pretty well understood and easily guarded against. When smutty grain is threshed, the infected seeds are broken, and the smut being of an adhesive nature attaches itself to the sound grain, and when this is sown, the fibrils of the smut pass upward through the stem, and infect the crop. In like manner, if sound grain be put into bags or boxes which have contained smutty grain, or if it be threshed on a floor on which smutty grain has been lately threshed, it will be infected. These causes of the disease should therefore be avoided by all prudent farmers.

If clean seed be sown in land that is not itself infected the crop will be free from smut; but it is difficult to secure clean seed as one kernel of smutty wheat contains as many as forty million spores of smut. Seed must be cleaned, which is done either by

washing off the adherent spores by alkaline washes, or by destroying the vitality of these spores by steeping the seed in poisonous liquids, or by plunging it into hot water. Of course in the latter cases the steeping must not be continued long enough to kill the seed itself. Thus the seed may be allowed to soak for a day in a solution of 1 lb. of caustic potash or 24 lbs. of hardwood ashes in 6 gallons of water, then washed, drained and dried by stirring slaked lime, gypsum or wood ashes with it. Or four bushels of seed may be stirred up with a solution consisting of one pound of copper sulphate, blue vitriol, to 4 quarts of water, and dried as before. Or the seed may be dipped for five minutes into a bath of scalding water at a temperature of 135° F.

4. *Ergot*.—This is an unnatural enlargement of the grains of wheat, by which they are converted into a black spongy substance about twice the length of the ordinary kernel, and of a very poisonous nature. This disease, like rust and smut, results from the growth of a parasitic fungus in the wheat plant.

Ergot does not usually destroy any large proportion of a crop, but when not attended to, may make it useless or deleterious by its poisonous properties. When observed, the grain should be sifted through sieves sufficiently small to retain the enlarged ergot grains. This should be attended to whether the grain be intended for the mill or for seed.

It is said that low moist lands are more subject to ergot, and that in such lands the disease may be removed by thorough draining. This view, which seems to be confirmed by experience in this country, deserves the attention of farmers whose fields are infested by this nuisance.

5. *The Wheat Midge or Weevil* has in recent times been the most destructive of all wheat blights. It is improperly called weevil; the weevils, properly so called, being a tribe of beetles, the young of which destroy corn in granaries. It is only by a careful study of the habits of a creature of this kind, that we can hope to counteract its ravages.

The observations of naturalists in England, where the creature has been much longer known than in America, have proved that the destroyer is the larva or grub of a minute midge, which deposits its eggs in calm summer evenings, on the chaff scales, whence the little grub when hatched creeps inward to the young grain, on whose juices it feeds. When full grown it descends to the soil and passes the winter in the ground. The following experiments and observations made many years ago, and I believe the first which clearly established the facts of the case, will suffice to give a view of the habits of these creatures.

A quantity of the larvæ were procured, full grown and in that motionless and torpid state in which they usually appear when the grain is ripe. A portion of these larvæ were placed on the surface of moist soil in a flower pot. In the course of two days the greater number of them had descended into the ground, previously casting their skins, which remained at the surface.\* I afterwards ascertained that they had penetrated to the depth of more than an inch, and were of a whitish color, softer and more active than they had previously been. The fact is thus established, that these apparently torpid larvæ, when they fall from the ripe wheat in autumn, or are carelessly swept out

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\*Some observations of Dr. Fitch, and Mr. D. J. Browne, render it probable that the skin is sometimes cast in the ear before descending to the ground.

from the threshing floor into the barn yard, at once resume their activity, and bury themselves in the ground.

The larvæ thus buried in the ground were allowed to remain undisturbed during winter and spring, the flowerpot being occasionally watered. About the end of June they began to reappear above the surface, in the winged form; the little grubs creeping to the surface and projecting about half their bodies above it, when the skin of the upper part burst and the full grown winged midge came forth and flew off. This completes the round of changes which each generation of these little creatures undergoes, and we have thus actual evidence of each stage of its progress from the egg to the perfect insect.

The perfect midge is a pretty little creature, its body being of a bright yellow color like that of the larva, its two large wings perfectly transparent with iridescent reflections, its eyes black, and its antennæ or feelers long and jointed; the male is smaller than the female, and has its antennæ ornamented with hairs. The flies are most active in calm and warm evenings, when they may sometimes be seen in clouds over the wheat fields. British observers say that the female deposits her eggs within the chaff; but here, they generally appear to be deposited without.

However we may dread the destructive powers of the midge, we cannot withhold our admiration from the singular instincts with which it has been endowed. The female insect depositing her eggs where food and shelter are provided for the young brood; the larvæ when shaken from their summer abode by the storms of autumn, at once entering on a new and untried life in the soil; and the chrysalids working their way to

the surface in the ensuing summer, to assume their winged state in time for the new crop of wheat, display a series of adaptations which may convince us, that, however annoying in the meantime to us, a creature so gifted cannot be without important uses in the economy of nature.

It is evident that if no check were opposed to the increase of these creatures, they must ultimately, in every country where they occur, consume the whole or nearly the whole of the wheat crop. There are however such checks, some in natural causes, and others in expedients which may be adopted by man.

In Europe the larvæ of several small parasitic insects prey on those of the midge, and no doubt greatly limit their increase.\* Dr Fitch has observed one such enemy of the midge in the United States. In this country, in cold and bare winters, it is probable that many perish; though it is quite an error to suppose that wet weather can kill the larvæ when in the ground. Moisture in the ground, indeed, seems to be essential to their life. Windy or stormy weather at the season when they are on the wing, must also greatly interrupt them in depositing their eggs. Accordingly they are observed to be most abundant in *sheltered* situations, and elevated and airy places are less liable to suffer from their attacks.

It appears from what has been said above respecting the habits of the midge, that during the greater part of its existence it is beyond the control of the farmer. He cannot prevent it from depositing its eggs, nor can he extract the larvæ from the growing crop; and in the ground in autumn and winter they are almost equally beyond his reach. *He can*

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\*See a paper by Mr. Billings in the Canadian Naturalist, vol, 1, p. 459.



*however destroy as many of them as he can house with his grain.* In this country, as in Britain, the full grown larvæ remain in the chaff until the grain is ripe, or until they are shaken to the ground by the first violent storms of autumn. When grain is observed to be infected, it should be attentively watched and cut so soon as this can be done without serious loss. In this country wheat is often left till it is too ripe; over ripe grain being much inferior to that which is earlier cut in the quantity and quality of its flour; and when the weevil is present there is a double gain in early cutting. It would also be advisable whenever it is possible, to reap, rather than cradle, the grain, in order to avoid shaking out the insects. The wheat should be threshed on a close barn floor which will not allow the larvæ to fall through, and when the grain is cleaned, *all the chaff and dust separated from it should be burned*, or if the chaff be saved for fodder, it should be *kept dry*, and none of it allowed to be mixed with the litter or thrown on the manure heap.

This method costs little trouble, causes no loss, and if faithfully followed out, would greatly diminish if not altogether prevent the losses occasioned by the weevil. It is worthy of attention, even in cases where the crop is only affected to a small extent. The midge often destroys a fifth, fourth, or even a third of a crop, without exciting much attention, and it is only when almost total loss ensues that great alarm is excited; but even these partial losses are not of small importance, and by destroying the larvæ in a season in which only a fourth of the crop is lost, we may perhaps prevent a total loss in the next season. It is true that when this precaution is neglected, Provi

dence, kinder to the farmer than he is to himself, may by some of the natural causes already mentioned, check the increase of the destroyers; but this will not always occur, and certainly furnishes no excuse for neglecting the means of safety which are placed within our reach.

As an illustration of the saving which can be effected by destroying the larvæ which are housed with the grain, I may mention that the friend who furnished me with specimens for experiment, informed me that from the wheat of eight acres he had obtained about *four bushels* of larvæ of the weevil. After making a large deduction for dust mixed with them, this quantity must have contained about 150 millions of the insects. If these insects, instead of being burned, had been scattered over the ground, they might, if the ensuing season had proved favorable to them, have destroyed the greater part of the wheat crop on the farm.

Various other expedients for the destruction of the midge have been proposed or adopted. When the flies are observed to be on the wing they might be prevented from depositing their eggs by kindling fires on the windward side of the field, or by agitating the grain by stretched lines carried by men or boys, in the calm evenings when the midges are most active. These however are clumsy and troublesome expedients, though, when they can be attended to, they may do much good. It is also probable that if the ground were deeply ploughed, after the larvæ had fallen upon it in autumn, they might be too deeply covered to permit of their escape in the spring. In the ordinary system of rotation, however, this could not be done without losing succeeding hay crops; and it is doubtful

if it would be very effectual. Perhaps the most effectual remedy ever proposed, is that of discontinuing the culture of wheat for a year, and thus depriving the midges of the necessary food for their larvæ. This is however an expensive expedient, and it requires the consent of all the farmers in the district affected. In the great majority of cases, it might be rendered altogether unnecessary, if the method of destroying the larvæ already described were generally adopted.

The most popular remedy hitherto tried has been late sowing in the case of spring wheat, and early sowing in that of winter wheat, so as to have the wheat in blossom too late or too early for the insect. This, however, in the case of spring wheat, subjects the grain to rust, and necessitates the use of early varieties of grain, which are not usually so heavy or productive as others. In the case of winter wheat, it renders it more liable to the attacks of the Hessian fly. It is also probable that in a few years the habits of the creature and the date of its appearance will *change to suit the lateness or earliness of the grain* which forms its food, and then the late sowing will prove quite ineffectual. It is also deserving of notice, that bearded varieties suffer less than the bald, as the awns obstruct the insects in depositing their eggs.

The facts above stated may be summed up as follows :

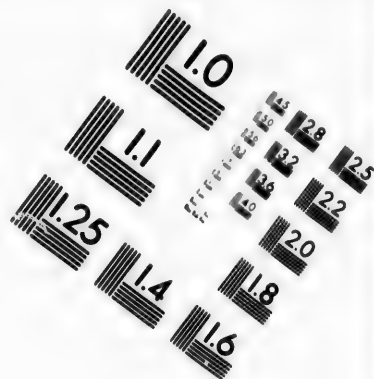
- (1.) The insect deposits its eggs on the grain about the time when it is in flower, and usually in the evening.
- (2.) The larva when hatched attaches itself to the young grain and prevents its growth.
- (3.) When full grown it becomes stiff and torpid, and if left long enough falls to the ground.

(4.) It buries itself in the ground and thus passes the winter.

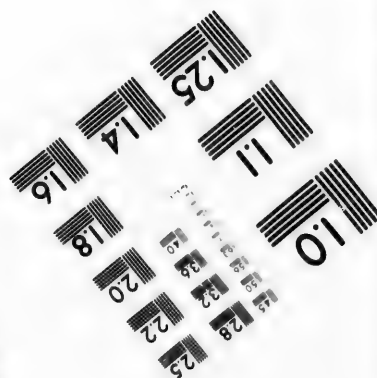
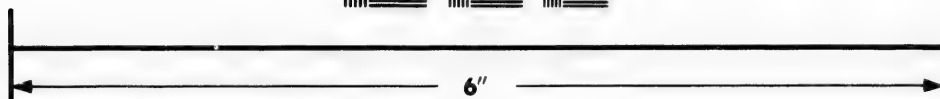
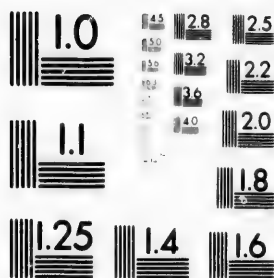
(5.) In spring, it emerges from the ground as a perfect insect, in which state, if the weather be favorable, it seeks the growing wheat for the purpose of depositing the germs of a new brood.

Lastly, though there are many partial remedies, the only sure one is to *cut early and destroy all the grubs found after threshing the grain*. To ensure safety, this should be kept up as regularly as the washing of seed wheat to avoid smut.

5. The Hessian fly is a relative of the wheat midge, and at one time threatened, like it, to destroy the culture of wheat. Its ravages have, however, in late years materially diminished. It attacks the stems of the young or half grown plants, establishing itself at the base of the shoot or in the joints, and when abundant wholly destroys the crop. The eggs, according to the best observations, are deposited on the leaves, whence the little larvæ or maggots when hatched make their way downward between the leaf and the stem. There are two broods, one produced from eggs deposited in winter wheat in autumn, the other produced from eggs deposited in spring, and attacking both spring and winter wheat. The best remedies are careful tillage and preparation of the ground, and abstaining from sowing on lea land, wheat grown on which is especially liable to be injured. Burning the stubble and ploughing it under, rolling the young wheat, mowing it in autumn or cutting it in spring, and late sowing, are all remedies that have been recommended, especially in the case of winter wheat. There can be no doubt however that the principal cause of the excessive multiplication of this



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insect is the want of any rational system of rotation of crops ; and the introduction of this usually arrests its ravages.

Several parasitic insects prey on the larvæ of the Hessian fly and greatly diminish its numbers.

6. *The Army Worm* is a naked caterpillar of the cut-worm tribe, of a gray color, with black and brown bands. Their native haunts appear to be meadows and similar places, where they devour the leaves of grass, but in some seasons they migrate in immense numbers to the grain fields and strip the grain of its leaves. When full grown they pass into the pupa state, under clods and in the ground, and emerge as plain gray moths. The injuries inflicted by these creatures are usually quite local. The only way of arresting their progress seems to be by digging narrow and deep ditches across their path, and killing them as they accumulate in these ditches.

7. Wheat is attacked by the larvæ of many other insects. Those of certain little flies of the genus *Chlorops* establish themselves in the stem. Other flies of the genus *Oscinis*, in their larva state, eat the young grain. Several beetles, moths and neuropterous insects also prey on it. None of these have however been so destructive as the midges, and the habits of many of them are very imperfectly known.

8. *The Oat Aphis* is a little plant louse which appears in vast numbers on wheat, oats and other grains, and often causes much alarm and inflicts some injury on the crop, though not usually to a great extent. It appeared in great abundance in Canada in 1861.

Wheat, long the staple crop of Canada, has ceased to be profitable in the older provinces, partly through exhaustion of the soil, partly through the increased



ravages of enemies, especially the midge, but chiefly through the fall of price in the markets of the world, due to the large amounts annually produced in countries newly accessible to the commerce in breadstuffs. How much does it cost to produce a bushel of winter wheat in Canada? Let us investigate two cases. First, let the crop be fall wheat preceded by summer fallow. Then there may be one deep ploughing, followed by harrowing and rolling, one gang ploughing with harrowing and rolling, one going over with the cultivator, one harrowing, one drilling in of seed wheat and timothy together, followed in the spring by broad-casting clover, then harvesting and housing the crop, threshing and preparing for market. Of these operations it would be fair to charge the crop of hay that will succeed with one-half of cost of cultivating, of harrowing once, of rolling once, and of drilling in seed. It would also be fair to charge one-half year's interest of the value of land occupied, and one-fourth of wear and tear of implements to the hay crop. There remains as the cost of raising and housing the crop of one acre of fall wheat, 1st ploughing, \$3; 2nd ploughing, \$1; two harrowings and one rolling, \$1.20; one-half cost of cultivating, of harrowing once, of rolling once, and of drilling in seed, \$1; cost of harvesting, \$2.25; cost of seed, \$1.20; three-fourths of wear and tear of implements, say \$1.50; 6% of value of land, worth say \$50 per acre, for one year and a half, \$4.50; total cost in the barn, \$15.65. The cost of preparing for market and marketing may be set down at 5c. a bushel. The average yield of one acre of fall wheat in Ontario is 22 bushels grain and a ton and a half of straw. If the straw be valued at \$4 a ton the net

cost of raising a bushel of wheat will be between 48c. and 49c., say  $48\frac{1}{2}$ c. plus the value of the nitrogen, phosphoric acid and potash removed in the grain. At the values stated above this will be in each bushel, for nitrogen 1.2 lbs. at 15c., 18c.; for phosphoric acid .55 lbs. at 10c.,  $5\frac{1}{2}$ c.; for potash .37 lbs. at 5c., 2c.; a total value of  $25\frac{1}{2}$ c. for these materials. The cost then of a bushel of wheat to the farmer is  $74\frac{1}{2}$ c., and if he can succeed no better than this he cannot afford to raise wheat for less than this price per bushel. If, however, he can raise as good an average crop as is done at the Agricultural College in Guelph, namely 27 bushels per acre, with 2 tons of straw, the cost per acre for labor, for wear and tear of tools and for rent of land remaining the same, the cost per bushel of wheat under these heads will be reduced to  $28\frac{1}{2}$ c. To this add cost of threshing, cleaning and marketing, 5c. a bushel, and value of material deported from the land,  $25\frac{1}{2}$ c., and the farmer will be able to sell wheat without loss at 59c. a bushel.

Suppose, however, that the land is kept clean and that a crop of wheat is to succeed a crop of peas. The cost of preparing the land will be greatly reduced, the wear and tear of implements will be correspondingly reduced, and the crop of wheat will be chargeable only with one year's rent of the land. Suppose further, for simplicity's sake, that none of the cost of preparing the land is charged against the hay crop, and that the wear and tear of implements is charged as before. Then the cost of putting in the crop will be, one gang ploughing, \$1 per acre; one harrowing, 40c.; one rolling, 40c.; drilling in seed, 40c.; wear and tear of implements, \$1.50; 6% of value of land for one year, \$3; harvesting, \$2.25; cost of seed,

\$1.20; total cost per acre of crop delivered in barn, \$10.15. If the returns be estimated as before, the cost of raising a bushel of wheat will be for labor, rent and wear and tear of implements, etc., until the wheat is stacked in the barn, 19c. with the smaller crop, and with the larger crop 8c. a bushel. Adding the cost of threshing, cleaning and marketing at 5c. a bushel as before, and of material deported from the farm at 25½c., the farmer can sell wheat without loss at 50c. a bushel in the first case, and 39c. a bushel in the second case. Indeed, if the land be clean, a crop after peas of 13 bushels of wheat with straw in proportion per acre is, in the long run, more profitable than 22 bushels after a bare fallow; and 17 bushels after peas is as profitable as 27 bushels after the bare fallow.

N.B.—Let the pupil verify the foregoing statements. Let him also calculate the cost per bushel of wheat-growing in the actual circumstances of the farmers in his neighborhood, where, in all probability, a different mode of preparing the land would be adopted, where the cost of each operation would be differently estimated, and where also land has a value differing from that assumed above.

## § 2. Oats.

The organic part of the kernel of the oat very much resembles that of wheat. Oatmeal contains 10 to 12 per cent. of gluten or an analogous substance, and is scarcely inferior to wheaten flour as an article of nutriment. In its inorganic ingredients or ash, it differs from wheat in proportion though not in kind; and, if grain alone be considered, a crop of oats requires from the soil nearly twice the amount of

inorganic matter required by wheat. It is therefore a great mistake to suppose that the oat is so much less exhausting than wheat, that the farmers can afford to overlook this effect. The oat, however, can take nourishment from raw and undecomposed vegetable matter, such as sod, peat, etc., from which wheat can obtain little nutriment.

As in the case of wheat, silica, alkalies and phosphoric acid are the principal ingredients of the ash. Silica and potash are, however, removed in larger quantity than by wheat. The oat also carries off from the soil a larger proportion of gypsum; hence it thrives in gypseous soils, or in sour soils which contain sulphuric acid, after they have been limed. The quantity of bone-earth required by the oat is, however, less than that required by wheat.

The above remarks show the proper place of the oat in the rotation to be that which it usually bears in the ordinary Scottish rotation, viz: the first grain crop after ploughing up the sward. It is well fitted for this, not only by its power of extracting nutriment from the decaying sod, but also by its dense shade, which prevents to a great extent the growth of weeds and grasses. This last character, as well as its great demands on the soil for inorganic food, unfit it for sowing with grass seeds, or occupying the place of wheat in the rotation.

It is barbarous farming to extract two successive crops of an exhausting grain like the oat from any ordinary soil, or to take a crop of oats and then let the land run out into grass. Nothing but dire necessity can excuse these practices, which are unhappily too prevalent. The manure produced from the oat straw, or its equivalent, should in all cases be restored

to the soil in the succeeding year, for a green crop. If this be done, the soil is improved, rather than deteriorated.

Our country is well adapted to the growth of oats, and this applies even to those parts of it in which wheat is uncertain. Oats must therefore always form a prominent object of attention to our farmers; more especially in the colder and less productive districts.

Few crops require more frequent changes of seed than the oat. When cultivated for a number of years in the same soil in our climate, it acquires a thick outer husk at the expense of the kernel, and becomes more liable to dust-brand. Experience has proved that the best change of seed is that imported from Scotland; and no oats are superior for this climate to the early varieties of that country. They are thin-skinned and heavy, and bear cultivation here for five or six years before they acquire the appearance and defects of run-out oats. Indeed, for two or three years after importation, they greatly improve in size and appearance, though probably not in actual value.

Oats should be sown as early in the spring as the ground will admit, and be cut when the straw of the head turns yellow while the stalk below is green. From 2 to 2½ bushels per acre will be enough of seed.

The Black or Tartarian oat is chiefly recommended by its earliness. It is inferior as a mealing oat both in quantity and quality, and though in some quarters a preference is given to it as food for horses, there can be no doubt that the white is more nutritious. Much loss is also sustained in this country by the cultivation of those lean, chaffy and bearded oats, that have been run out by long cultivation, and mixed by carelessness with better varieties.

The dust brand and the grubs of the Harry-long-legs often injure the oat crop, but I am not aware that they have ever become so destructive as to call for any special attention on the part of the cultivator.

The cost of raising a crop of oats may be estimated as follows: One ploughing of greensward, in autumn if possible, \$2 per acre; one gang ploughing in spring, \$1; one harrowing, 40c.; one rolling, 40c.; one drilling in of seed, 40c.; cost of seed, 70c.; wear and tear of implements, \$1; interest on land, \$3; cost of harvesting, \$2.25; total cost per acre, \$11.15. The average crop in Ontario is 35 bushels per acre; the average of 11 years on a good farm was 50 bushels and the maximum on the same farm was 70 bushels. The price per bushel for threshing and marketing may be stated at 5c. per bushel, and the value of manure is 12c. (see example 185). The straw may be estimated at  $1\frac{1}{2}$  tons in the first case, 2 tons in the second and  $2\frac{1}{2}$  tons in the third, and may be valued at \$5 a ton. This makes the total cost of raising a bushel of oats in each case to be 28c., 20c. and 15c.

### § 3. Rye.

Rye, like wheat, is of two kinds, winter and spring; but the latter is but seldom grown in this country.

The grain of rye does not differ very materially in its composition from that of wheat. It contains, however, more sugar and less gluten; and the gluten is of a somewhat different nature, at least in its mechanical properties, and is less fitted for the production of a well-raised bread. Rye takes less from the soil than wheat. The difference is principally in the straw, which contains less lime, silica, and bone-earth than that of wheat. The ash of the grain differs very slightly from that of wheat.



Rye prefers light soils, and may be made very useful in bringing in light ground unfit for the growth of wheat. It also forms a substitute for wheat when the latter grain appears to be in danger of being destroyed by weevil; but in ordinary circumstances it should not be sown on ground capable of producing wheat, being much inferior to that grain as an article of food. Rye straw is of little or no value as fodder; but is excellent for thatching, collar-making, and basket-making, and makes tolerable hats.

Rye may be sown later than wheat because of its greater hardiness, and should be harvested when the straw is yellow, except at the green knots.

It is said that rye has occasionally suffered from the wheat fly, but slightly. Its worst enemy is the ergot, a fungus-like enlargement of the grain, which, like the ergot of wheat, renders it black and poisonous. When the ergot is observed, it should be carefully sifted from the grain before grinding. The principal inducing cause of ergot appears to be too great moisture in the soil; and where this is the case, the culture of rye should not be persisted in, when the ergot is found to appear constantly or often in it.

The cost of preparing an acre of land for rye is less than for wheat, both because it may be grown on lighter and more easily worked land, and because the tilth need not be so fine as for wheat. But as an offset to this the straw is less valuable to the farmer. The cost of preparing an acre for a crop of rye, of seeding it, and of harvesting it, is about \$9.50, against which must be set the value of 2 tons of straw at \$3 a ton, leaving a net cost for one acre of grain \$3.50. A crop of 30 bushels per acre will cost the farmer 12c. per bushel in the barn. To this must be added



the cost of threshing and marketing, 5c., and of material deported from the farm, 21c., a total net cost of 38c. per bushel.

#### § 4. Barley.

Barley is either two-rowed, four-rowed, or six-rowed, according to the number of vertical rows of grain in the head. The two-rowed is the favorite English barley, the four-rowed called bere is cultivated to some extent in Ireland and the North of Scotland, but the six-rowed is that which is best adapted to our Canadian agriculture and is that which is all but universally cultivated.

The grain of barley much resembles in its composition that of wheat, but it contains less gluten and more starch and sugar. It is therefore less nutritious, though in wholesomeness it yields to no other grain. In many parts of the country, barley is little known except for its use as pot-barley, and its value as a material for the manufacture of alcoholic liquors. Its culture as a bread corn should perhaps be more widely extended. To most persons the flavor of barley bread is very agreeable, and barley-meal pottage is certainly superior to that of Indian meal or rye flour. Barley is also an excellent substitute for wheat, when the latter is in danger from weevil. It is a very sure crop, and very early; and suits admirably for sowing with grass seeds. Its true place in the rotation is the same with that of wheat. It may, however, be sown in lea land, though it is not so suitable for this as the oat.

Because of its larger yield barley takes rather more from the soil than wheat, and the excess is principally in silica, bone earth, lime, alkalies and gypsum. It is

therefore a mistake to suppose that a good crop of barley does not require a soil in good condition, but as barley sends its roots much along the surface and not to a great depth, it is less dependent on deep tillage than wheat. Alkalies and especially soda are highly favorable to its growth, and it prefers light and loamy soils.

Barley may be sown as soon as the ground is ready in spring, and should be harvested as soon as the straw is white and the ears are curved downwards.

The cost of raising a crop of barley after a clean hoed crop may be thus estimated: One gang ploughing, one harrowing, one rolling, drilling in seed, wear and tear of implements and interest on value of land, \$6.20; the cost of seed may be 90c. and of harvesting \$2.25 per acre, \$9.35 per acre in all. A crop of 30 bushels per acre, with two tons of straw worth \$4 a ton, will therefore cost the farmer 4½c., say 5c. a bushel, stacked in the barn. To this add cost of threshing and marketing, say 5c. a bushel, and value of deported nitrogen, potash and phosphoric acid, 17c. a bushel. The net value of a bushel of barley to the farmer is thus brought up to 27c. a bushel.

### § 5. Indian Corn.

An inspection of the table, page 141, will show that maize, being very rich in oily and fatty matters, has a very high value as an article of food, especially for fattening stock. In this climate, Indian corn requires a light, deep soil, and a good supply of rich manure. Gypsum should be strewed on the top of the hills or drills, both as a direct manure, and to prevent the escape of the ammonia from the manure beneath. The most convenient place of corn in the rotation is

as a green crop, since the treatment which it requires and its effects on the soil are not very different from those of the turnip and carrot. Good corn may, however, be raised in lea land, and also after green crops in place of wheat, but in both cases manure is required in addition to that already in the soil. It is better to plant corn in drills, like turnips but farther apart, than in hills. Nothing is gained by having the plants crowded; they require much air and light. In stiff soils they should be well earthed up, or the seeds may be planted in the tops of the drills, but in light land they should be planted on the level. Frequent hoeing is very beneficial, as also cleaning and earthing with a light plough or cultivator. Pumpkins are often planted with corn; many good farmers, however, believe that the gain in pumpkins scarcely repays the loss in corn. This must depend on the degree to which the leaves of the pumpkins deprive the corn of air and light, and on the impediments which the vines offer to the proper culture of the corn.

It is useful to cut off the feather or bloom, the male flower of the corn, after it has served its purpose in fertilizing the ear. This should be done when the beard or tassel of the ear begins to wither, but not before; and as few large leaves as possible should be cut off with the top, as all the leaves are useful in aiding the growth of the ear. The tops make good fodder, and when deprived of them the corn is less likely to be broken down by autumnal storms.

Corn is liable to injury by smut, allied to that which infests wheat. The smutty ears, which are quite conspicuous by their deformity, should be broken off, carried away and burnt, as, if thrown upon the ground, the spores will continue to develop. Smutty

corn should not be fed to animals, as it is unwholesome, and even poisonous.

Corn is subject to the attacks of grubs which burrow in the stalks, after the manner of the larvæ of the Hessian fly in wheat. The easiest remedy appears to be sowing sufficiently thick to allow spare plants for the grubs. When, however, time can be spared to pull up and destroy every plant that shows by the fading of the leaf the presence of the grub, the labor will be repaid by the diminished number of grubs in the ensuing season. The seed is also sometimes destroyed by squirrels, birds, etc. This may be prevented by steeping the seed in anything that makes it distasteful to these depredators. Steeping in urine, soft soap or nitre, and drying with lime or gypsum, are said to be serviceable; but smearing with tar has also been practised, and is stated to be more certain.

The meal from corn raised in this country is finer and more delicate in flavor than that from Southern and Western corn. This should cause it to bring a higher price; and should in connection with the productiveness of the crop, commend its culture to all farmers who have the sandy or loamy soils which it prefers. Even if too late to ripen, it is valuable for fodder, if cut immediately after the frost strikes it.

Corn is now largely employed as a green crop or for ensilage purposes. More detailed reference to corn in this relation will be found in Chapter XVI.

#### § 6. *Buckwheat.*

The extended culture of this plant cannot be considered as an indication of improved or prosperous agriculture; since this grain is generally a substitute for others, or a refuge from the want caused by

impoverishment of the ground. Buckwheat, however, is a grain of some value, and, if properly used, need have no connection with bad farming.

The kernel of buckwheat contains from 6 to 10 per cent. of gluten, and 50 of starch, with 5 to 8 per cent. sugar and gum. (*Norton*). It is, therefore, inferior in nutritive power to all the grains previously noticed; though still a very valuable article of food. A portion of the inner husk is usually ground with the flour; giving a dark color, and bitter taste. When this husk is entirely removed, the flour is pure white, and so dense as to resemble rice flour, or potato farina; and, either in bread or cakes, is a light and agreeable article of food. Of course the quantity of this fine flour is much less than that of the coarse kind; but the refuse is useful for fattening hogs; and if good flour were more generally made, its use would be extended and its price enhanced.

Buckwheat does not make great demands on the soil. Its large leaves obtain a great part of its nutriment from the air; and it requires but a small proportion of mineral matter. Hence it can be successfully cultivated on very poor soils, though it certainly thrives better on those that are rich. From the dense shade which it produces, it is an admirable exterminator of weeds; and hence, makes a good preparatory crop for weedy soils or poor grass land. The scattered seeds of the buckwheat itself are, however, apt to be troublesome in the succeeding crop. In England and the continent of Europe, buckwheat is often usefully employed in reclaiming poor soils, by ploughing it in when green. A large amount of vegetable matter is thus given to the soil; and I have no doubt this would be found useful in bringing in light and worn-out soils in this country.

The stems and leaves of buckwheat, cut green, make good summer food for cattle; but are less nutritious than clover. Large heaps of buckwheat husks are sometimes seen near mills. They should be composted and applied to the land; and would be found to be excellent manure.

### § 7. Beans and Peas.

These plants are remarkable for the large amount of nutriment which their seeds contain, and which is greater even than that of the best wheat or oats. Hence, though they cannot in ordinary circumstances form so large a part of the crop as the cereal grasses, they are important objects of the farmer's attention.

The *French or dwarf kidney beans* are very valuable as a green crop. Their produce is not very large, but is highly nutritive; and they have the merit of being the best table substitute for the potato. They require compost manure, and to be kept clean from weeds. They may very well occupy a portion of the drills prepared for turnips, as the same manures and mode of culture suit them, and the time for sowing is also the same. French beans should not be in the ground till the buds of fruit trees are bursting, as they are very liable to be nipped by late frosts, or rotted by cold damp weather. The China, white Canterbury, or small white calavanca, are the best for this climate. The imported calavancas are rather late; but by picking the earliest ripe pods for seed, they soon become sufficiently early. Kidney beans contain 23 per cent. of legumin, a substance analogous to gluten, and 43 per cent. of starch. (*Johnston.*)

The *horse bean* may be cultivated in the same manner as the French dwarf, but must be sown early.



It is used exclusively, at least in the dry state, for the food of animals, especially horses and hogs. It is more nutritious than the oat, and better for working horses; though at first it is often difficult to induce them to eat it. The small horse or tick bean of England thrives well in this country; though some farmers here prefer the early cluster, or some other variety of the broad horse bean, as being more productive, and ripening equally well in this climate. The straw of these beans, if chopped or broken up, is excellent fodder, little inferior in nutritive properties to ordinary hay.

Beans of all kinds require from the soil a large quantity of potash and lime, principally for their stems. Manures and composts, containing much of these substances, are, therefore, especially adapted to them.

The *Pea* approaches very nearly to the bean, in point of nutrition, and perhaps excels it in fattening power; and its straw, or haulm, if saved in good condition, is stated to be little inferior to meadow hay. The straw of the pea contains a large proportion of lime; and hence, this substance, or composts containing it, form very proper top-dressings for a pea crop. The pea occupies a different place in the rotation from the bean; for, though the dwarf varieties may be cultivated in drills as a green crop, it ordinarily thrives very well if sown broad-cast, in any tolerably rich land that is not overrun with weeds. Peas have, indeed, no regular place in a rotation, and are somewhat uncertain. They are therefore rather giving way, in the best farming districts, to the culture of beans and turnips. The pea often suffers much from the pea-worm, which is the larva of a small species of moth, or in other cases of a little



beetle. No treatment applied to the seed can avert the attacks of these creatures, since the eggs from which the larvæ are produced are deposited by the parent insects in the blossom, or young pod. Where, indeed, farms have become infested with this pest, it is best to cease for a few years the attempt to grow peas. The best palliative is to sow very early; and it seems worthy of enquiry, whether early peas, sown in early spring, might not be gathered in sufficient time to permit a crop of buckwheat to be taken from the same ground. At all events, buckwheat might be sown and ploughed in to enrich the soil.

§ 8. *Turnips, Carrots, Mangel Wurzel, etc.*

These, in most of the countries of the northern temperate zone, form staple green crops, and probably contribute as much to the money returns of the farmer as any other crops. In this country, as yet, their capabilities have been very imperfectly tested; though there can be no doubt that their culture is on the increase. They demand, however, more humidity in the air than is found far inland, and they are consequently better adapted to sea-board districts, or to well watered soils. In reference to these crops, Johnston remarks, with much truth: "To raise them the farmer must prepare, must save, and must husband his manures; he must feed his cattle better, and will thus be led to improve his breeds of stock; while the better harvests of grain he obtains after the green crops, will make these green crops themselves more profitable, and therefore objects of more useful attention. The spread of green crops in England and Scotland has been invariably the prelude to agricultural improvement, and to an amelioration, not only

in the practice, but in the circumstances also of the farmers."

All these roots contain a large proportion of water; and their nutritive portion is made up of albumen, sugar, gum (pectin), and starch. These substances are present in various proportions, according to the kinds of roots cultivated, and the nature of the soil and manures. All of these root crops require from the soil much potash, soda, lime, bone-earth, and gypsum, as well as some vegetable matter; and the manures intended to afford these substances should, when practicable, be in the form of well rotted composts. Long manure will rarely afford a heavy crop. Artificial manures, especially salt, gypsum and superphosphate, are very valuable in the culture of green crops. About 200 lbs. of each of the manures mentioned above may be sown broadcast on each acre shortly before the sowing of the seed. Root crops require, for perfection, a deep and fine tilth, and a soil kept free from weeds. They are therefore more dependent on continuous labor than any other agricultural crop, and are the most costly crops that the farmer raises. Carrots and long-shaped mangels require a deeper soil than turnips and globe-shaped mangels.

The proper place of green crops in a rotation is between two crops of grain; as, after oats and before wheat or barley. The oats will have greatly smothered and starved out weeds by their dense shade, and the manure abundantly furnished with the root crop, well assimilated to the soil, will aid the development of the wheat or barley. The preparation of the soil for a green crop in a good clay loam will consist of gang ploughing the stubble as soon as possible after

the preceding crop is taken off, repeated harrowings to destroy sprouting weeds, spreading a heavy dressing of barn yard manure well rotted, ridge ploughing in the fall—at the same time subsoil ploughing if the ground be in suitable condition, harrowing as soon as possible in the spring, cross ploughing with the gang plough, sowing artificial manure, and drilling in the seed. Then for the destruction of weeds the horse-hoe must be kept going between the drills from the time the seed appears until the development of foliage renders this impracticable. When the young plants are firmly established, hoe by hand and thin out the rows, leaving the finest plants and destroying all weeds. The mode of harvesting will depend on the character of the crop.

*The Turnip.*—The following quotations are from Judge Peters' "Hints to the Farmers of Prince Edward Island": "The Swedish turnip, rutabaga, appears to be best suited to this climate, especially on account of its property of keeping well in winter.

"As to the best time for sowing Swedes, there is much difference of opinion; they may be sown from the 20th of May to the end of June; they continue to increase in weight until the frost compels us to pull them, and therefore, the earlier they are sown, the heavier will be the crop. When sown in May, I have always found them escape the fly; but the best protection against this insect is thick sowing—never sow less than three lbs. of seed to the acre, and you will seldom be without sufficient plants after the fly has done its work. Aberdeen Yellows may be sown from the first to the end of July.

"The turnip has two very troublesome enemies,—the turnip flies (two species of *Altica*), and the cater-

pillar of a moth which attacks the leaves in autumn. Against the ravages of the fly, the following expedients may be adopted: *First*,—late sowing, the fly being most destructive in May, and the early part of June. *Secondly*,—abundant seeding, which enables the plants to start more vigorously, gives a better chance of selecting strong plants when thinning, and affords food to the fly without losing the crop. The farmer should remember that the fly makes a point of taking its share first, and consequently he must provide for it if he wishes to have any left for himself. *Thirdly*,—sowing while the ground is moist, immediately after the drills are made, and selecting, if possible, the commencement of moist weather. *Fourthly*,—watering the ground when the seed is sprouting, with diluted urine, soap suds, or guano and water, or the drainings of a manure pile. *Fifthly*,—sprinkling lime, wood ashes, soot, or guano over the young plants, or on the drills when the plants are appearing.

“By adopting these methods, or such of them as may be practicable, a crop may always be secured; and if any vacancies occur, they can be sown with white turnips until the beginning of August, or they can be supplied with plants of mangel wurzel, a bed of which is very useful for this purpose, as they will stand transplanting in any weather. Various dressings for the seed have been recommended, but these do little to protect the leaves; and I have known some of the most offensive of them—as for instance, codfish oil and sulphur—to fail entirely in driving off the insects. It may also be observed, for the encouragement of those who wish to extend their turnip culture, that *large fields* usually suffer less than *small patches*, for a very obvious reason.

"The worm, or caterpillar, has been found a difficult enemy to deal with, as it sometimes attacks the turnip (chiefly the white and Aberdeen varieties) in immense numbers, and devours them very rapidly. In England, flocks of young ducks turned into the fields have been found to destroy the grubs; and it is likely that watering with soap-suds, lye, lime water, etc., would do something toward diminishing their numbers.

"Some complain of turnips being difficult to keep; those who find them so keep them too close; with proper management there is no difficulty in keeping any quantity. They should be put in piles in the field when first pulled, and covered with tops or straw, and a little earth. Here they will sweat a little. A dry day should be chosen to cart them to the root-house. My root-house is dug four feet deep, and then the roof pitched from the earth, and covered with seaweed and earth, well sodded over; the floor formed of slabs and longers, raised six inches from the bottom, and divided into three divisions. It will contain about two thousand five hundred bushels of roots, and I generally fill it full, and have never lost any turnips. In the top there is a chimney, which is never shut, night or day, during the winter; the vacancy below, and the partitions, allow all the confined air to ascend, and as it is constantly escaping through the chimney, no frost comes down. Any one who will ventilate his root-house in this way, will find the turnips as sound in June as when first put in. The situation of the root-house is a matter of importance; it should be attached to the barn, and entered from the barn; this will save a deal of labor in carrying the roots to the cattle during winter. Some

store them in their cellars, which are the worst places that can be selected, as they are generally too hot and close to preserve the turnips, too far from the barns for convenience, and the gas which escapes from them renders the air of the houses unwholesome.

"The *Mangel Wurzel* (*mangold*), is, of all green crops, the best for milch cows. It produces a large quantity of milk without communicating to it any disagreeable flavor, and it keeps remarkably well in winter. The mangel wurzel transplants well ; and its thinnings may be very properly used to fill up any gaps that may occur in turnip drills. It requires a somewhat stronger and deeper soil than the turnip, and in light soils the yellow globe variety will be found more profitable than the common long red.

"The *Carrot* is also a most profitable and sure green crop, especially in the lighter kinds of soils, and is admirably adapted for the winter feeding of working cattle and horses.

"The *Parsnip* is well deserving of culture as a field crop. It thrives in the heavier kinds of soil, and yields a large quantity of very nutritious roots, which should be left in the ground during winter, and may be dug in early spring, at a season when little succulent food can be procured for stock. It would form an admirable resource in case of deficiency or loss of other roots stored in autumn. The carrot, parsnip, and mangel wurzel should be sowed as early as possible. I have even sowed them on a small scale in autumn, with success."

As has been remarked, green crops are the most costly crops that the farmer raises. Indeed, it has been asserted that they do not pay for themselves directly, that they are profitable to the farmer only



through the manure which, when fed to live stock, they supply for other crops, and through the extirpation of weeds which results from frequent tillage.

The cost of raising an acre of any green crop may be stated approximately thus: One ridge and subsoil ploughing, \$3; two gang ploughings, \$2; three harrowings, \$1.20; seed and drilling seed, \$1.20; horse-hoeing twice, \$1.60; hand-hoeing twice, \$4.50; cost of hauling and spreading 15 tons of barn-yard manure, \$3.75; cost of distributing mineral manures, 50c.; cost of harvesting roots, \$8.00; rent of land and wear and tear of implements, \$4.00; total cost exclusive of value of manures, \$30.25. Value of manures, 15 tons of barn-yard manure, containing 200 lbs. of available nitrogen, 200 lbs. of potash and 100 lbs. of phosphoric acid, of which one-half is soluble, \$47.50; 200 lbs. of 80% muriate of potash yielding 100 lbs. of potash, would cost \$5; 200 lbs. of superphosphate yielding 20 lbs. soluble phosphoric acid \$3.20; and 200 lbs. gypsum, 50c.; total value of manures, \$56.20. The total cost of raising a bushel of turnips, of carrots, or of mangolds will be found by adding the cost per bushel for labor, for interest on land and for wear and tear of implements, to the cost per bushel of manures. The former cost is easily ascertained beyond the possibility of dispute; but the latter cost is calculated in two ways, namely, either by charging the green crop with a certain estimated share of the total value of manures supplied, or by charging the value of the manures carried off in the green crop. The first way is open to serious objection in that the proportion of manure left over for succeeding crops is less, the larger the green crop. It has been assumed that one-half



the manure supplied is left behind by the green crop, and this is a just estimate when the manuring is liberal and the crop only average. But for large crops it is an erroneous estimate. The largest crop of turnips reported from the Agricultural College, Guelph, is 900 bushels per acre. Such a crop (see table, p. 141) will remove from the soil 162 pounds of nitrogen, 276 pounds of potash, and 83 pounds of phosphoric acid, while the amount supplied in manure as given above is 200 lbs. of nitrogen, 300 lbs. of potash and 120 lbs. of phosphoric acid, of which 50 lbs. is in the insoluble state. The requirements of the crop for other substances will be rather more than sufficiently met. It is evident that very little of the manure furnished is left by such a crop for the crop that is to follow.

The fairest way of estimating the cost in manure of the crop is to value the ash ingredients removed by it as has been done in arithmetical exercise 185. The cost then of raising a maximum crop of turnips, 900 bushels per acre, is for labor, rent and wear and tear \$30.25, divided by 900, 3.4c., and for manure 5.2c. (see rutabagas in example 185); total cost per bushel, 8.8c.

### *Examples.*

187. The maximum crop of carrots reported from the Agricultural College, Guelph, is 900 bushels, and of mangolds is 1,020 bushels; what is the cost of raising them per bushel?

188. What would be the cost per bushel of raising the average crop in Guelph College if the ground were worked as stated in the text above, the average being 635 bushels turnips, 595 bushels carrots and 797 bushels mangolds?

189. What is the cost per bushel of raising the average crop of Ontario, 420 bushels of turnips, 385 bushels of carrots, and 462 bushels of mangolds? The ground being less thoroughly worked, omit from your calculation one gang ploughing, one subsoil ploughing, one harrowing and one horse-hoeing; as mineral manures are not generally employed omit the cost of distributing them.

### § 9. Potatoes.

The potato contains in its tuber a larger proportion of nutriment than the turnip or carrot, chiefly in the form of starch with a little albumen. It requires the presence in the soil of potash and lime in considerable quantity. Much more than one-half of the ash of the stem of the potato consists of these substances, and potash forms nearly one-half of the ashes of the root or tuber. Potash is contained in the stable manure usually applied to the potato, and in soils containing lime it thrives well, and is less liable to disease than in others. Some persons suppose that the application of lime and wood ashes causes the potato to be scabbed. This, I believe, is a mistake, but salt and door manure seem to produce this effect. Though the potato will thrive, when otherwise in a healthy state, with raw stable manure in contact with its roots, yet there can be no question that it grows better with rotted manure well mixed through the soil. It is probable that much of the efficacy of sea-weed, which is much used as a manure for potatoes on the sea coast, depends on the soda which it contains supplying the place of potash. The sea manure is thus very useful on the slaty soils; and on the granite soils, which contain much potash, the lime afforded by the

sea-weed is probably of more importance than the soda. Animal manures affording nitrogen are also very important to the vigorous growth of the potato, as to most other cultivated plants.

The potato of late years has had to contend with two most destructive enemies,—the fungus of the potato disease, and the potato bug.

The potato disease or rot is produced by the growth throughout the tissues of the potato plant of the mycelium of a fungus. The disease commences with the development of a very minute rough brown ball, the resting spore of the fungus, which, having been produced at the close of the previous season by the fungus, has lain dormant through the winter either in the ground, in crude farm-yard manure, or attached to the potatoes planted as seed. The mycelium produced by the development of the resting spore penetrates the sprouting potato, grows upward through the young plant, ramifies into every part, and soon through the stomata of the leaves protrudes, to the open air, branches bearing minute capsules that contain innumerable spores. These soon ripen, the capsules burst and countless millions of spores are drifted by the air to neighboring plants. Whenever they reach the leaves or green stems of potato plants, they begin to develop, and their mycelium penetrating by the stomata grows throughout the substance of the newly infected plant.

A little consideration will show how to explain the leading facts as to its mode of occurrence.

1. The general diffusion and simultaneous occurrence of the disease over extensive regions, is a remarkable fact.

2. The disease has usually attacked the crop at that

stage of the growth when the tops are fully formed, and the formation and filling up of the underground tubers are most rapidly proceeding.

3. The disease has usually first made its appearance in the leaves, and descended from these to the stems or roots. In the leaves and stems it appears in the form of death and decay of the tissues, very similar to that which results from frost, or the application of any poisonous substance. In the tuber, its progress can be distinctly observed, and is somewhat curious. The tuber consists of a vast number of little cells, or bags, filled with a fluid containing vegetable albumen and other substances in solution, and having small grains of starch floating in it. There are usually several of these starch grains in each cell. Through this cellular tissue pass bundles of vessels or tubes communicating with the eyes or bud on the surface of the potato. The disease usually commences at the surface, immediately under the skin, and usually near the eyes, and penetrates inwards along the bundles of vessels. Under the microscope it is seen to be accompanied by the growth of this minute parasitic fungus, analogous to that which causes mildew in wheat. From the vessels it spreads to the walls of the cells, and the fluid they contain becomes decomposed and blackened; and after all the rest has been reduced to a brown putrescent mass, the starch grains still remain entire. It has been observed in some instances, that in proceeding from the stem to the roots, the disease appeared first in the tubers nearest to the stem.

The ravages of all destructive fungi are much aggravated by any circumstances which diminish the vitality of the plants or animals on which they prey; and, on the other hand, whatever gives constitutional

strength to the plants or animals attacked tends to diminish the virulence of the disease produced by parasitic fungi. Hence, as tending to the general well-being of the potato plant, the following are very important *temporary remedies or palliatives*.

1. *Early planting*, and planting early sorts; because this gives greater probability of avoiding the effects of autumnal chills and rains. This remedy has been found very effectual in Nova Scotia.

2. *Change of seed*, especially from poor and cold localities to richer and milder situations. The Scottish low country farmers have obtained excellent results by importing seed potatoes from the bleak and poor highland districts.

3. *Selecting those varieties* which have proved *least liable* to the disease; and these will generally be found to be such as have been recently introduced, or lately procured from the seed.

4. *Planting in dry soils*, and underdraining more moist soils, if necessary to plant in them. The dry, sandy uplands of some districts have almost entirely escaped the disease, when the crop has been put in early.

5. Applying *well-rotted manure*, and ploughing it in, instead of putting it with the seed in the drills. *Guano* and composts made with *liquid manure*, have proved themselves better than stable manure. This and the two last remedial agents act by giving the plants a greater degree of healthy, general vigor, than they could derive from run-out seed, in wet soil, or in contact with rank manure.

6. *Planting in new soil* and the use of *mineral manures*. It is generally observed that the potato has been most healthy when planted in new, virgin

soil, before the unskilful agriculturist has extracted from it the stores of alkaline and other mineral manures remaining in it from the ashes of the forest. The composition of the ash of the potato at once explains the reason of this, as the table on page 141 shows.

Potash forms more than 50% of the ashes of the roots, and an examination of any table of analysis of the tops would show in addition to much potash a very large amount of lime.

Now these substances, potash especially, are plentifully supplied to the soil by the ashes of the woods, and are usually deficient in exhausted lands. Hence, if we apply to run-out or long cultivated soil, lime, wood-ashes, gypsum (sulphate of lime), common salt (chloride of sodium), bone dust (phosphate of lime), we supply it with some or all of the more important substances in the above table, and thus assimilate it to the virgin soil in which experience proves the potato to thrive best. I have found, by experience, that healthy potatoes (though not a large crop) could be obtained by planting with no other manure than a pint of unleached wood-ashes in each hill, in seasons when potatoes planted with ordinary manure were blighted.

For the same reasons it is, of course, unwise to raise successive crops of potatoes on the same soil. Whenever, on old land, a proper rotation of crops is not attended to, there is much greater likelihood of failure.

7. Storing in dry cellars is of the first importance, when the crop is infected. I have found that potatoes in which brown spots of disease were already formed, had the progress of the change arrested by being kept dry; and that the diseased spots dried up and lost their putrescent character.



8. Where there is no hope of otherwise saving a crop, the rotting potatoes may be grated or ground up, and the farina and starch saved. With a little extra washing, it will be nearly as good in quality, though usually less in quantity, than that from sound potatoes. Every farmer should have a grater or grating machine for potatoes, and in autumn should prepare a quantity of farina. It is excellent for children's food, puddings, to mix with flour for bread, etc., and it will keep for several years.

All the above, and probably other expedients, have been approved by experience as useful palliatives. In short, anything that tends to place the plant in a natural and healthy condition appears to give it a much greater power of resisting the cause of disease, whatever that may be.\*

Can any reason be assigned for that apparently universal weakness of constitution which more than forty years ago threatened to deprive us entirely of this much prized esculent? Is there anything in the past history or present condition of the plant, likely to produce such an effect? I have long thought that there is such a cause, and shall now proceed to explain it, in connection with the only means of counteraction which have suggested themselves.

Of all our crops, the potato alone has been continuously propagated by natural or artificial division of the plant. The tuber of the potato is a sort of underground stem, with eyes or buds intended to produce young shoots in the year following the formation of the tuber and with a store of starch, albumen, &c. to nourish these young shoots in the early stages of their

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\* To this I may add that when the disease is observed in the stalks, the potatoes should be dug at once. If they must be left in the ground, the stalks should be pulled out.



growth. These tubers, then, in the natural state of the plant, must serve to continue its existence from year to year, and to extend the individual plant into a group or bed of greater or less extent. But this process is not intended to be perpetual. The longest-lived forest tree must eventually die, and so must the group or stool of the potato, which, originally founded by a single seed from a ball, is only one plant increased in extent by a spontaneous division of its roots into detached tubers. It gradually exhausts the neighboring soil, until its own vital energy diminishes, and at length it will die out; and if a new plant occupies its place, it must be a seedling produced from the balls which have fallen on the spot.

Have we a right to expect that plants propagated, not by natural generation through the seed, but by perpetual division of the plant, should continue to be healthy for an indefinite period? We may not know the minute changes which bring about the debility of age, but we know that such debility does overtake plants as well as animals. Fine varieties of carnation, propagated by cuttings or layers, in a few years degenerate, and must be abandoned by the florist. The same happens to other florists' flowers, though in some more slowly. Grafting and budding fruit trees is but continuing the lives of individuals, and despite the vigor of the new stock, grafts from very aged trees of old varieties, show the debility of the parent. Hence, most of the finest fruits of a century or two ago have degenerated and become less worthy of cultivation, and have been replaced by new varieties from the seed. This seems to be one of the great laws of vegetable life; and accordingly, even those

plants which, like the potato, have been furnished with tubers to provide for the continuance of individual life, have also been provided with seeds to produce new individuals, and thus permanently continue the species.

Taking this view of the matter, we should rather wonder that the potato has lasted so long, than that it now fails. We can, in truth, account for its long duration only by taking into consideration the variety of soils and climates in which it has been cultivated, the frequent changes of seed, and the occasional raising of new varieties from the ball.

If, however, this cause has had any real influence on the plant, why has it not merely run out or died of old age, instead of contracting a malignant and fatal disease? The analogy of other vegetables leads us to believe that plants do not always simply die out under the influence of degeneracy or old age. The worn-out carnation loses the size and brilliancy of its flowers; the old varieties of fruit trees lose their vigor of growth, degenerate in their fruit, and become very liable to the attacks of parasitic fungi and animals; the ancient forest, its trees decaying at the heart, and overgrown externally with lichens, mosses, fungi, and excrescences, usually perishes by tempests or fires, before it undergoes the slow process of natural death. So with the potato. Under high cultivation, its starchy and albuminous parts, those which are valuable for human food, have been increased, while, by constant reproduction from the roots, the vitality of the living buds has been diminishing. The potato, at one time the most certain and hardy of crops, has gradually become tender. The "curl" and "dry rot" began many years ago to cut off the young shoots and

the planted tubers, apparently because there was not sufficient vegetative life to enable the living bud to control and use the abundant nutriment for it in the cells of the tuber. This difficulty was overcome in part, by changes of seed, planting the whole tubers, and other expedients; and the life of the plant was protracted a little longer, as might have been expected, to be attacked only by a worse disease.

I come now to the method which the above views would lead us to consider the only certain one, with a view, if not to the final extirpation of the disease, at any rate to its reduction to harmless dimensions.

*It is to cultivate the potato from the ball, for several generations continuously, until the hereditary taint is removed, and then to distribute the healthy tubers to such agriculturists as will pledge themselves to abandon entirely the culture of the present exhausted and diseased varieties.*

These views of the author, first published by him in the Report of the Agricultural Societies of Massachusetts for 1851, have since been often reproduced by various writers, and reduced to practice in the production of new varieties of the potato by cultivation from the seed—varieties which, possessing the vigor of youth, have successfully resisted the attacks of the potato disease, and have wholly superseded the worn-out varieties which preceded them.

At present the potato-bug is the greatest enemy of the potato crop; but it is successfully combated by Paris Green, a compound of copper and arsenic, and a most virulent poison. It is applied either by sprinkling a weak solution in water over the plants as soon as the bugs make their appearance, or by powdering the plants, preferably while wet with

dew or rain, with a mixture of flour or plaster of Paris with a small quantity of Paris Green.

The cost of raising a crop of potatoes may be reckoned, exclusive of manures, at a little more than that of a crop of turnips;—say \$34 an acre. The average potato crop in Ontario is 175 bushels per acre. This makes the cost per bushel irrespective of manures 19·4c a bushel, to which must be added for material removed from the soil 5·3c, making a total of 24·7c a bushel. If, however, a maximum crop of 250 bushels, be raised, the cost per bushel is reduced to 18·9c. Usually, every bushel of potatoes sold at less than 25c., is sold at a loss to the farmer.

#### § 10. *Clover and Grasses.*

In a country where the winter is long and severe, these must always be important crops; though, as already hinted, when treating of the climate, it is certain that the extended culture of root crops, to be fed to cattle and horses in winter, would very much lessen the present difficulties in this respect. I have already quoted the opinion of Professor Johnston on this subject, and now give an additional extract, on the former and present state of Scotland:

“The same state of things as now exists in New Brunswick, existed in Scotland, in connection with this branch of husbandry, about a hundred years ago. Cattle were killed at the end of summer, and salted for winter use, because the stock of hay at the farmer’s command was not sufficient to keep them through the winter months. The beef these cattle gave was so poor that it took the salt badly, was hard and indigestible, and kept badly in the brine. Now, the cattle are not killed in the autumn more than at other

seasons. The present modes of husbandry provide winter food for all the stock the farmer finds it convenient to keep. When killed, the beef or mutton is now of excellent quality; large quantities of both are forwarded, all the year through, to the southern markets; and it can be cured for the naval service, or for any other use."

It appears to me that, in the present state of our husbandry, the most important points to be considered in reference to hay crops, are, in the first place, the injurious practice of cutting hay from the same ground for a great number of years in succession; and secondly, the best modes of promoting and ensuring the growth of clover. To these subjects, therefore, I shall devote the remainder of my remarks under this head.

The skilful farmer should never forget that run-out hay land is in every respect unprofitable. It costs almost as much per acre for fencing, mowing, and raking as better ground, and yields little, and this of very inferior quality, possessing little nutritive power. In dry seasons, also, it cannot be depended on. Hence, one acre capable in a good season of yielding three tons, or two tons in a poor season, is far more valuable than six or seven that in a good season may yield, perhaps, one ton per acre, and in a poor season may fail altogether. Hay land should be sown out in good heart, and then not more than two crops should be taken, at least without some fertilizing top-dressing; and even with top-dressing, not more than three or four. After this, if it cannot be broken up, it should be left for pasture. Circumstances may render necessary partial deviations from this rule; but the principle should be considered as settled, that every

deviation will entail loss in the end. Every farmer, on ploughed land, can at least apply this principle to a part of his land—and the larger that part the better. In connection with this it must be remembered that good summer pasturage, independent of more direct benefits, does much to aid good winter keeping. Hay culture, without impoverishing the land, is, after all, not so difficult as may be imagined, if the produce be fed out upon the farm; for the liquid and solid manure of the animals that consume the hay, contains nearly all that the hay took from the soil; and if saved and restored, no impoverishment results. On the other hand, the grand secret of hopelessly and rapidly impoverishing the farm and the farmer is to crop the land in hay till it will bear no more, and then let the manure go to waste, or sell off the hay. Johnston, in his Report on New Brunswick, gives the following example of a prevalent error in this respect: "I visited the farm of a most intelligent gentleman, one of the best farmers in his neighborhood, and I believe most desirous to improve; who informed me that after one dressing with mussel mud, from the sea bank not far from his farm, he had taken one crop of potatoes or turnips, one of wheat, and eight successive crops of hay; and he seemed to think that the land had used him ill in not having given him more. For the first four crops, from such an application, a British rent-paying farmer would have been thankful and content; and in taking these, he would have been thought rather hard upon his land."

The timothy grass (herd's grass) usually cultivated in this country, is one of the best of grasses, in every respect. It is, however, often treated with injustice, by being allowed to remain too long before cutting.



Where there is a large crop to be cut, and few hands, mowing should, if possible, be commenced *before*, rather than after the flowering of the head,—which is the time when the grass contains the largest quantity of nutritive matter. It is true, however, that few grasses will bear late cutting better than herd's grass. Even when left to ripen its seeds, it is worth more as food than many of the light grasses of worn-out lands. The substances which this grass requires to be present in the soil are very much the same with those needed for grain crops. Its favorite ground is a moist and deep soil.

Clover is a most valuable adjunct to herd's grass, especially in the lighter soils; but the conditions necessary for its successful culture are as yet very imperfectly known in this country. The ashes of clover contain large quantities of potash, lime and gypsum. These substances must therefore be present in the soil. Clover loves a calcareous soil, and hence it is observable that in those soils which, from the vicinity of beds of lime and gypsum, are naturally rich in calcareous matter, clover thrives without any trouble. I place first, therefore, among the requisites for the successful culture of this crop, the presence of lime and gypsum in the soil. If not naturally present, they must be supplied artificially. The next requisite is a deep and dry soil. Clover sends its roots deeply into the ground, and will not thrive in shallow, wet soil. To fit it for clover, such soil should be drained and subsoiled. Thirdly, the leaves of the clover must not be destroyed by the scythe or by cattle in the autumn of the year in which it is sown. These leaves ought to be employed till the frost kills them, in preparing nourishment for the growth and strengthening



of the root; and if cut early with the grain, the plant is so enfeebled that it has little chance of standing in winter. In reaping, the wheat straw should be cut so high that the scythe or sickle shall not touch the clover leaves. This high stubble will also shelter the clover in winter. Of course no cattle or sheep should be allowed to enter the stubble fields in autumn. Fourthly, the ground should be rolled in spring, to press in the clover roots. Fifthly, after clover has been sown several times, in the ordinary course of successive rotations, the land becomes "clover-sick," as it is termed, and the crops fall off. Clover-sickness is due to the attacks of a minute eel-worm, which destroys the vitality of the root and stem. Whatever adds to the vigor of the plant enables it more successfully to contend with the foe, so that manuring with wood ashes, lime composts, and urine, have been found beneficial.

But, when ground has become thoroughly infected by the presence of this pest, no course seems to be open to the farmer except to abandon for some years, eight or ten, the cultivation of red clover on that spot.

Neglect of these facts is the principal cause of the two great evils complained of in this country in respect to clover, viz: the winter-killing of the roots, and the too early ripening and death of the top in summer. These losses are often attributed to particular varieties of seed; but they depend far more on the nature of the soil and treatment,—though of course, some unfavorable seasons occur, in which no management is altogether effectual; and as the natural life of red clover does not extend beyond two or three years, it cannot be expected to remain permanently in the land. Shallow, undrained, poor soils, which do not

allow the roots to become large and strong in the first year; destruction of the leaves of the first year in autumn; deficiency of lime and alkalies; and neglect of rolling,—are the principal causes of winter-killing; and the same causes, with the addition, in old farms, of clover-sickness, cause the crop to ripen prematurely.

Clover, like peas and beans, is a leguminous plant, that is, it produces its seed in pods, and like all leguminous plants it appears to nourish in small callosities on its roots a form of bacterial life that in ways ill understood as yet, has the power of assimilating nitrogen from the air, rendering such plants independent of the nitrogen of the soil, and, indeed, enabling them by their growth to enrich the soil in nitrogen, rather than, as all other plants appear to do, to impoverish it. The whole subject is one that is as yet under observation and discussion, and it is impossible to speak with the definiteness that all practical men must desire; but, perhaps, it is not premature to say, 1st, that a leguminous crop usually shows an amount of nitrogen in its nitrogenous material greater than it has taken from the soil and from the manures supplied to it; 2ndly, that this assimilation of nitrogen is due to the growth of microdemes which feed upon the carbonaceous matters accumulated in the soil, and the growth of which is specially favored by leguminous plants; 3rdly, that this is the most plausible explanation yet offered of the value of clover as a fertilizer for grain crops; and, 4thly, that as a practical lesson derived from these considerations, every farmer should arrange that in turn every part of his land should be made to carry at frequent intervals, a crop of peas, of beans, of vetches, or of clover in one of its forms, red clover, white clover, alsike, etc.

The place of a crop of clover and timothy, in a rotation, is after wheat, rye, or barley, the seed, in the case of spring grains, being sown with the grain, or in the case of fall grains, the timothy may be sown with them, and the clover broadcast and lightly harrowed in on the green grain in the spring. For one or two years after the grain with which it is sown has been cut, hay may be cut, and the land pastured for a year or even longer afterward, before breaking up for oats.

It is difficult to estimate the cost of a crop of hay, for two or three reasons; first, the labour of preparing the ground must be done for the grain, even if the hay crop were not to follow; secondly, no further labour is expended on the ground for the second crop of hay and for the pasture that may follow; thirdly, it is not possible to state quantitatively the relation of the clover to nitrogen, as it is not believed that all the nitrogen of the clover crop is abstracted from the soil. However the hay must be charged at least with the cost of seed, and, when clover is sown in the spring upon fall grain, the cost of sowing and harrowing must be charged against it, then the cost of saving the hay, the rent of the land, the wear and tear of implements, and the value of the ash ingredients and nitrogen of the crop must also be charged against it.

The account of the hay crop will stand something like this: seed and seeding, \$5.00; harrowing, 40c; mowing, making, and hauling hay, two years, \$4.00; rent of land, two years, \$6.00; wear and tear of implements, \$2.00; total \$17.40. The average hay crop of Ontario is  $1\frac{1}{2}$  tons of mixed timothy and clover, three tons for two years, costing \$5.80 for

labour, etc., to which must be added for manure, if the crop be half timothy and half clover, \$8.14; so that \$13.94 a ton is the cost of growing mixed timothy and clover. If two tons per acre be mowed each year, the cost will be reduced to \$12.49 a ton.

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## CHAPTER XVI.

### SOILING AND SILOS.

#### § 1. *Green Fodder.*

Pasturing stock is not profitable employment of arable land. The amount of food which stock can find on three acres of grazing land is not equal to that which can be grown as a crop on one acre. Temporary pastures that follow hay as usually grown from timothy and clover seed only, contain but few and haphazard species of grass, and these do not afford sufficient variety to enable the pasture to meet vicissitudes of season, especially the drouths to which in Canada we are somewhat liable. Consequently such pastures cannot be depended on; if they are made to carry as much stock as they can in rainy weather, the stock will be apt to suffer from insufficient food in dry weather. Besides much more of the manure of grazing animals is wasted than of stall fed animals. On the other hand, pastures and grazing animals require but little labour, while the process of growing a crop and of cutting it and distributing it to animals involves much labour.

Accordingly, agriculturalists have sometimes resorted to soiling, that is to the growing of such crops as peas and oats, oats and vetches, rye, maize, clover, lucerne, or millet, which are cut green and fed to stock in stables or in paddocks too small to provide sufficient pasture. In this way abundant food is supplied to animals at all times, their strength

is not wasted in searching for it, and, consequently, working cattle and horses, milch cattle and fattening cattle, are kept in better condition. But the confinement and want of exercise eventually tell against the health of young cattle and cattle used for breeding.

Not only is the process of growing soiling crops, of cutting them and distributing them laborious, but the labour of cutting and distributing can neither be intermitted nor postponed, no matter how urgent the occasion. Consequently the system of complete soiling has never obtained in Canada, except in the treatment of city horses and cows. But in all well conducted farms, on which a sufficient amount of live stock is carried, partial soiling is necessary and should become universal. Soiling crops, with the exception of rape, are usually either gramineous or leguminous. Of the former, in addition to the grasses commonly cultivated for hay, may be mentioned winter rye, oats, millet and maize; of the latter, red clover, lucerne, alsike, vetches and peas are employed. Mixtures of gramineous and leguminous plants are frequent for soiling purposes; as, orchard grass and red clover, timothy and red clover as for hay, timothy and alsike, oats and peas, oats and vetches.

Winter rye is especially valuable because it may be used in the spring, and the ground that has borne it may carry a crop of millet, Hungarian grass, corn or rape, immediately following it. Red clover and orchard grass yield two, and lucerne three or four cuttings in one season. Rape is valuable as a late soiling crop, eaten off by sheep or cattle where it grows. The special advantage of corn is that it yields more food per acre than any other soiling crop, except, possibly, lucerne.

§ 2. *Ensilage.*

In a climate so rigorous as ours, where for half the year all kinds of stock must be stabled and fed, it is a matter of no small importance to the health and good condition of live stock to furnish them with a sufficient amount of succulent food for use with the hay and grain, that must be their principal dependence. Where roots can be profitably grown, they may be fed to stock, but in many parts of Canada soil and climate are uncongenial to roots, so that the root crop is held to be uncertain and unprofitable. Casting about for means to remedy this deficiency, farmers, within the past fifteen or twenty years, have begun to imitate, on the large scale, with green fodder, the process which is exemplified on the smaller scale, by the housewife who preserves fruit and vegetables by sealing them in air-tight cans.

It has become abundantly clear of late years that all those changes taking place in dead organic substances, which are called decay, fermentation, or putrefaction, are dependent on the development, growth and multiplication of minute forms of life, both animal and vegetable, but especially vegetable. If these living forms can get no access to the dead organic matter, it will not undergo putrefactive change. These living forms never spring up of themselves; they are not generated by decay; they are produced by the development of germs which are the offspring of parents like themselves. These germs abound in the air, in the water and in the soil, wherever life is or has recently been. But they are not everywhere. They are not found, for instance, at great heights in the air, as on the summits of lofty mountains. They



may be killed by high temperatures or by poisonous gases, and they may be excluded from confined spaces by sealing, or even strained out by layers of fibrous material, as cotton wool. All these facts are exemplified in many ways. The housewife boils the fruit which she intends to can, that she may destroy the germs which, if sealed in with the fruit, would inevitably cause moulding, fermentation and decay. She seals the cans while hot, that she may exclude all such germs for the future. The surgeon washes his hands and his instruments in a solution of corrosive sublimate in order that he may kill all adherent germs and avoid their introduction into a wound; and he covers the wound itself with lint that has been sterilized, that is that has had adherent germs killed, in order to strain all such germs out of the air that finds its way to the injured part.

When a very large mass of dead stalks and leaves is thrown into a heap in the moist state, its surface is exposed to all the influences of the atmosphere; but its inner part is acted on in a way quite different. At first the oxygen included in the mass acts upon the carbonaceous matters present, and carbon dioxide is formed, while at the same time the temperature rises and the living germs begin their work. But in the dense interior of the mass the heat generated, and the carbon dioxide produced are imprisoned. The temperature rises until the oxygen is all consumed, by which time it has risen high enough to destroy many of the living germs; and the rest deprived of the oxygen on which their active life depends, and surrounded with an atmosphere of poisonous carbonic gas, are either killed or rendered inert. In the interior of the mass, then, crushed down by its own weight, the generation

of heat and all fermentations quickly cease, and change being arrested in the interior, it may be months or even years before decomposition, slowly creeping inward from the exterior, can reach the centre ; more especially because the living germs are largely filtered out of the air by the strawy mass of dried-up leaves and stems that form the outside covering. The core of such a mass of fodder would be so little changed after many months as to be much relished by stock as an accompaniment to hay. It is evident that the process of thus preserving fodder in a succulent state would be much more economical if outside waste were diminished by piling the mass in a receptacle air-tight below and at the sides. This is now usually done, and much fodder is annually preserved in the green state.

Material so preserved is called silage, the air-tight receptacle is called a silo, the verb to ensile is used to assert the act of packing away silage, and the word ensilage is used as the name of that act.

The silo should have its sides so constructed as to exclude air and frost. This is secured by constructing its walls of two thicknesses of boards with tar paper between. The structure must be strong and firmly braced to resist the very considerable inside pressure due to the weight of the material. The inside walls should be smooth, so that the silage may sink easily and compactly downward as it yields to the weight above. The roof of the silo must be weather-proof. Doors should be made in the roof or in the gables for the introduction of the material to be ensiled and for ventilation, while other doors ranging at intervals from top to bottom of one side will afford facility for removing the silage for use. The earthen floor of the

silo must be so far raised above the general surface that water will not stand upon it.

Any green fodder may be used for filling the silo. Clover, quite green, even dripping with rain, may be put into the silo, as also green oats or any of the grasses. But experience shows that corn sown in rows three feet apart and cut when the ears are beginning to glaze, gives the richest and most abundant silage from a restricted area.

The corn, if corn be ensiled, is cut, brought to the silo, run through a cutter which cuts it into lengths of about half an inch and is piled into the silo so as to keep it well filled up at the sides. As the silage will begin to mould at the surface in three or four days, the work of filling must go on with only an occasional interruption of a day or two until it is complete. Sometimes a covering of straw or of marsh grass is spread upon the surface when the silo is full, and well trampled down to exclude air as much as possible. But it is not necessary to take this trouble. If the upper surface is left exposed a few bushels of silage will spoil at the top, but will preserve the rest from injury. Of course in that case the farmer will remove the ears of corn from the last load ensiled. If clover be ensiled there is danger that it may be too dry when put away.

The silage soon heats, sometimes reaching a temperature of 140° F. in the middle, and, softened by the heat, subsides under its own pressure into a compact mass, shrinking about 30% of its height and weighing after shrinkage between 50 and 60 lbs. to the cubic foot. The silo may be left undisturbed for a month to ripen its contents; but may then be opened, and will furnish nutritious and palatable food for many months to come.

Many modifications of the mode of ensilage are in use. Sometimes the silage is made of uncut green fodder, piled in a huge stack, firmly compacted, and finished off with a haystack on the top. Sometimes it is piled in underground pits, trodden and rolled firm and covered with earth. Each modification has its special advantages which will appear in practice, but the principle is the same in every case, viz: by the size of the mass and its close compression to exclude air from the interior.

One acre of corn skilfully treated will produce 20 tons of silage equal in feeding value to about  $6\frac{1}{2}$  tons of hay. The cost of production will be about as follows: For ploughing sod in the fall, \$2; gang ploughing in spring, 75c.; harrowing, 25c.; seed and seeding, \$2; horse-hoeing twice, \$1.25; cutting, hauling, running through cutter, and piling in the silo, \$5; rent of land \$3; wear and tear of implements and rent of silo, \$4.50, a total cost of \$18.75, say \$1 a ton. The value of the substances removed from the land is not reckoned, as these will be returned to it in manure. If the silage were sold, which is never the case, the value of the substances removed from the ground, \$14, would be added, and would make the net cost approach \$1.75 per ton.

## Appendix.---Synonyms.

Scientific chemical nomenclature has been much modified of late years, but the older names still survive in commerce and occur in works on agriculture, works many of which are of great value. In the preceding chapters the aim has been to use an approved modern terminology, although, especially in quotations from other works, there are a few deviations. To diminish the risk of confusion in the mind of the student who consults other works or who examines trade circulars and catalogues, meeting diverse names for the same substance, a little table of synonyms is here appended, in which are placed first names as used by Roscoe, which are the names chiefly used in this little work, followed by other names, placing last any that now occur in commerce only. The last names have not always the definiteness of the first names in the lists; thus carbonic acid sometimes means  $\text{CO}_2$ , called preferably carbon dioxide, and sometimes  $\text{H}_2\text{CO}_3$  to which (page 90) the term properly belongs; the term potash sometimes means potassium monoxide,  $\text{K}_2\text{O}$ , sometimes it means potassium hydroxide or caustic potash,  $\text{HKO}$ . Names thus misplaced are enclosed in parenthesis below.

The student should, however, observe that many of the names are fundamentally identical. Sometimes elements of the names are merely inverted in order, as chlorhydric for hydrochloric, or chloride of sodium for sodium chloride. Sometimes an adjective form is preferred to the noun form of a word, as sodic sulphate for sodium sulphate.

The table is restricted to the elements and their compounds discussed in chapter V.

#### ELEMENTS.

Oxygen, vital air.  
 Nitrogen, azote.  
 Carbon, charcoal, diamond.  
 Iron, ferrum.  
 Sodium, natrium.  
 Potassium, kalium.  
 Aluminum, aluminium.

#### BASES.

Sodium monoxide, sodic monoxide, soda.  
 Sodium hydroxide, sodic hydroxide, caustic soda, (soda).  
 Potassium monoxide, potassic monoxide, potassa, potash.  
 Potassium hydroxide, potassic hydroxide, caustic potash, (potash).  
 Calcium oxide, calcic oxide, quick lime.  
 Calcium hydroxide, calcic hydroxide, slaked lime.  
 Magnesium oxide, magnesian oxide, magnesia.  
 Ferrous oxide, protoxide of iron.  
 Ferric oxide, sesquioxide of iron.

#### ACIDS.

Nitric acid, hydrogen nitrate, aquafortis.  
 Hydrochloric acid, chlorhydric acid, muriatic acid, spirit of salt.  
 Carbonic acid, hydrogen carbonate.  
 Sulphuric acid, hydrogen sulphate, oil of vitriol.  
 Phosphoric acid, trihydrogen phosphate, tribasic phosphoric acid.

## SALTS.

Sodium nitrate, nitrate of sodium, nitrate of soda, Chili saltpetre.

Sodium chloride, chloride of sodium, sea-salt, rock-salt, common salt.

Sodium carbonate, carbonate of sodium, carbonate of soda, (soda), washing soda.

Hydrogen sodium carbonate, bicarbonate of soda, (soda), baking soda, (saleratus).

Sodium sulphate, sulphate of soda, salt cake, Glauber's salts.

Monosodium phosphate, dihydrogen sodium phosphate, superphosphate of soda.

Bi-sodium phosphate, hydrogen bi-sodium phosphate, neutral phosphate of soda.

Ter-sodium phosphate, trisodium phosphate, subphosphate of soda.

(There are the same variants of the scientific names of the potassium salts as of the soda salts. Trivial names of two of these salts follow.)

Potassium nitrate, saltpetre.

Hydrogen potassium carbonate, (saleratus).

Calcium carbonate, calcic carbonate, carbonate of lime, chalk, marble, limestone.

Calcium sulphate, calcic sulphate, sulphate of lime and when combined with water, gypsum, alabaster.

Monocalcium phosphate, monocalcic phosphate, superphosphate of lime.

Bicalcium phosphate, bicalcic phosphate, dicalcic phosphate, reverted phosphate of lime.

Tercalcium phosphate, tricalcic phosphate, bone ash, apatite.

Magnesium sulphate, sulphate of magnesia; combined with water, Epsom salts.

Ammonium chloride, sal ammoniac.



**NOTE.**—As the sole aim of the reviser of this book is the direction of pupils in our schools to the systematic study of agriculture, the most important and the most interesting of all our arts, he will gladly receive from practical men and from teachers hints to its improvement; and, as far as the time at his disposal admits, he will clear up difficulties in the minds of teachers, and suggest ways of solving problems and conducting illustrative experiments by communications to the Educational Record.

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## Answers to the Arithmetical Examples.

N.B.—When answers are not exact, the figure given in the last decimal place is the nearest to the exact answer, whether greater or less than it.

- 1—1;  $\frac{1}{2}$ ;  $\frac{1}{4}$ ; 4; 20; 40 cubic inches.
- 2—60; 240; 259·2; 518·4; 2160 pounds.
- 3—500; 400; 200; 100; 22·2222; 4·6296; 3·4722; 2·3148; 1·1574; ·5787; ·3858 pounds.
- 4—14·43 times.
- 5—535·68 grains.
- 6—13·07 cubic feet.
- 7—593·96; 37·1; 519·72; 816·7; 1317·77 grains.
- 8—1·1088; ·1386; 2·9106; 9·84; 7·623 ounces.
- 9—3·2258; 2·9093; 46·5484; 3·3249; 1·3113; 2·1158 cubic inches.
- 10—·902; 14·43; 1·0307; ·6559; ·4066 volumes.
- 11—2; 1·129; 1·493; 1·879; ·6907; 1·191; 1·8668.
- 12—3·2258; 1·6129; 1; 1·1088; 2·46; ·0693.
- 13—·0693.
- 14—1·5246; ·0693.
- 15—·58905; 1·0256.
- 16—·4158; 1·0395; ·9979; ·9997.
- 17—49·4577 cubic inches; 6·4516 cubic inches; ·1304.
- 18—·1584; 1·0015; 1·933.
- 19—·99996; oxygen is required in very small amount.
- 20—If a column of mercury 30 inches high, resting on a base of one square inch, weighs 14·715 lbs., a column one inch high, on the same base, weighs one-thirtieth of 14·715 lbs., that is, ·4905 lbs.
- 21—15·205; 14·96; 14·519; 13·9302 lbs.
- 22—14·372; 14·136; 14·396 lbs.
- 23—1913·012 lbs.
- 24—8·45 lbs.
- 25—282·19 lbs.
- 26—·4785 grains; 1·544 cubic inches.

- 27—474·8 lbs.  
 28—60 lbs. per square inch.  
 29—1564 grains.  
 30—Nitrogen exerts a pressure of 28 lbs. on the square inch, and oxygen 7 lbs. There are in each cubic foot of the mixture 988·93 grains of nitrogen and 282·55 grains of ox.  
 31—277·23 cubic inches.  
 32—14·284 lbs.  
 33—433; 58·86; 58·427 lbs.  
 34—52·8 lbs.  
 35—6·917 lbs.  
 36—3·74 lbs. pressing the paper downward; therefore the water would run out.  
 37—14·284 lbs.; 29·12 inches; 4180·9 lbs.  
 38—116·45 feet; 115·83 feet.  
 39—81·5 feet.  
 40—·08; ·164; 7·2; 4198·4 quarts.  
 41—34·56; 70·85; 3110·4 cubic inches.  
 42—1·49; ·64; 89·9 grains.  
 43—745; ·32; 44·95; 2·98; 1·28; 179·8; 1·44; ·6; 86·9; 1·54; ·66; 92·9 grains.  
 44—1555·2 cubic inches or 776·75 grains of carbon dioxide; and 17·23 cubic inches or 5·49 grains of nitrogen.  
 45—·82 cubic inches or ·298 grains of oxygen, and 1·6 cubic inches or ·509 grains of nitrogen.  
 46—·8; 1·8; 1·25; 13·55.  
 47—·81; 1·79; 1·24.  
 48—1 cubic inch; 2·6.  
 49—·61 cubic inch; 2·7.  
 50—4·1; 6·43; 6·85; 8·91; 24·19 cubic inches.  
 51—523°; 1014°; 1505°.  
 52—147·6°.  
 53—412·7°.  
 54—34·15 inches.  
 55—32·77; 32·24; 31·61; 30·41; 29·85; 28·78; 23·98 grains.  
 56—225 heat units.  
 57—1800 heat units.  
 58—92°; 1200 heat units.  
 59—7½ ounces; 50 heat units.  
 60—17 minutes 12 seconds.  
 61—1 hour 13 minutes 36 seconds.  
 62—17 minutes 55 seconds.  
 63—212½.  
 64—40½ degrees.

65—6 heat units.

66—72°; 140 heat units.

67—101·75°; 70·25°; 66·43°.

68—17·46 lbs.

69—136·2°.

70—It will begin to freeze in 3 minutes 16 seconds, and will be completely frozen in 11 minutes 50 seconds more.

71—2 hours 31 minutes.

72— $\frac{1}{2}$  lb.

73—46·27°.

74—75·5°.

75—87287 tons.

76—18925 tons.

77—82009 tons.

78—24183 tons.

79—3·9 grains; 25%; 76%.

80—At a quarter past two dew begins to form, there will be no hoar frost, for the temperature falls no lower than to 33°.

81—83·84%; 43·37%.

82—C,  $\frac{1}{11}$  lb.; O,  $\frac{1}{11}$  lb.

83—Ca, 1600 lbs.; O, 640 lbs.

84—Ca, 10 lbs.; C, 3 lbs.; O, 12 lbs.

85—C, 24 lbs.; O, 64 lbs.

86—4; 5·5 lbs.

87—With 8 lbs. of oxygen, forming 9 lbs. of water.

88—Ca, 30 lbs.; C, 9 lbs.; O, 36 lbs.

89—CO<sub>2</sub>, 132 lbs.; Ca, 120 lbs.

90—C, 48 lbs.; O, 64 lbs.

91—14 lbs. of carbon monoxide unite with 8 lbs. of oxygen to form 22 lbs. carbon dioxide.

92—1 $\frac{1}{5}$  oz. of O will be needed;  $\frac{3}{5}$  oz. of H<sub>2</sub>O and 1 $\frac{1}{5}$  oz. of CO<sub>2</sub> will be formed.

93—37·1 grains.

94—16 oz.; 14 oz.; 22 oz.

95—6·17; 98·71; 86·37; 135·73 grains.

96—145·59 lbs.

97—819·6 lbs.

98—16; 1·1088.

99—14; 9702.

100—(a) That two volumes of hydrogen and one of oxygen make two volumes of vapour of water; (b) that oxygen is bivalent; (c) that the specific gravity of vapour of water is nine times that of hydrogen, and compared with air is 1·6237; (d) that water consists of two parts by weight of hydrogen united

with sixteen parts by weight of oxygen, or, more simply, one-ninth of the weight of water is hydrogen and eight-ninths is oxygen; (e) that three volumes of hydrogen and one of nitrogen make two volumes of ammonia gas; (f) that nitrogen is trivalent; (g) that the specific gravity of ammonia is eight and a half times that of hydrogen, or, compared with air, it is .589; that ammonia consists of three-seventeenths hydrogen and fourteen-seventeenths nitrogen. See pages 57, 58, 77, 80, 81 and 83.

101— $1\frac{9}{8}$  oz.

102—O, 8;  $8\frac{8}{9}$ ; 55.4;  $1777\frac{7}{9}$  lbs. H, 1;  $1\frac{1}{9}$ ; 6.9;  $222\frac{2}{9}$  lbs.

103—1 volume H, 1 volume N, 3 volumes O; by weight 1 part H, 14 parts N and 48 parts O.

104—384 lbs. O; 112 lbs. N; 8 lbs. H.

105—35.5 and 2.46.

106—16.

107—4.176 oz. and .882 oz.

108—1 volume each of H and Cl make one volume HCl; 2 parts in 73 by weight are H, the rest being chlorine; 1.265.

109— $36\frac{2}{3}$  lbs.

110—22; 1.5246.

111—About six ten-thousandths.

112—27.66 tons.

113—7.54 tons.

114—80 lbs.

115—16 lbs. S;  $32\frac{8}{9}$  lbs. O;  $1\frac{1}{9}$  lbs. H.

116—32; 2.218.

117—2 lbs. 8 oz.; 4 lbs. 7 oz.

118—1 lb. 11 oz.; 6 lbs. 2 oz.

119—23 oz. Na; 8 oz. O;  $8\frac{3}{4}$  grains H.

120—46 lbs. Na; 71 lbs. Cl; 7 ft. 8 in. high.

121—(a)  $2\frac{7}{3}$  oz.; (b)  $3\frac{1}{3}$  oz.; (c)  $3\frac{2}{3}$  oz.; (d)  $5\frac{5}{3}$  oz.; (e)  $3\frac{1}{3}$  oz.; (f)  $5\frac{5}{3}$  oz.; (g)  $3\frac{2}{3}$  oz.; (h)  $2\frac{2}{3}$  oz.; (i)  $2\frac{2}{3}$  oz.

122—(a)  $2K + O = K_2O$ ; (b)  $K + H_2O = H + KHO$ ; (c)  $K + Cl = KCl$ , or  $K_2O + 2HCl = H_2O + 2KCl$ , or  $KHO + HCl = H_2O + KCl$ ; (d)  $K_2O + 2HNO_3 = H_2O + 2KNO_3$ , or  $KHO + HNO_3 = H_2O + KNO_3$ ; (e)  $K_2O + H_2CO_3 = H_2O + K_2CO_3$  = water and potassium carbonate, or  $KHO + H_2CO_3 = H_2O + KHCO_3$  = water and hydrogen potassium carbonate; (f)  $K_2O + H_2SO_4 = H_2O + K_2SO_4$  = water and potassium sulphate, or  $KHO + H_2SO_4 = H_2O + KHSO_4$  = water and hydrogen potassium sulphate; (g) either  $K_2O + 2H_3PO_4 = H_2O + 2KH_2PO_4$  = water and two molecules of mono-potassium phosphate, or  $KHO + H_3PO_4 = H_2O + KH_2PO_4$ ; either  $K_2O + H_3PO_4 = H_2O + K_2HPO_4$  = water and

bi-potassium phosphate, or  $2\text{KHO} + \text{H}_3\text{PO}_4 = 2\text{H}_2\text{O} + \text{K}_2\text{HPO}_4$ ,  
either  $3\text{K}_2\text{O} + 2\text{H}_3\text{PO}_4 = 3\text{H}_2\text{O} + 2\text{K}_3\text{PO}_4$  = three molecules of  
water and two molecules of ter-potassium phosphate, or  
 $3\text{KHO} + \text{H}_3\text{PO}_4 = 3\text{H}_2\text{O} + \text{K}_3\text{PO}_4$ .

123— $3\frac{1}{3}$  oz.; 9 grains; 56 grains.

124—14 lbs. N; 39 lbs. K.

125—\$87.92.

126—\$4.98; \$4.18; \$3.14; \$3.39; \$2.69.

127—\$63.27.

128—(a)  $829\frac{3}{4}$  grs. K,  $1701\frac{0}{7}$  grs. O; (b)  $696\frac{3}{4}$  grs. K,  $285\frac{5}{7}$  grs. O,  $17\frac{5}{7}$  grs. H; (c)  $523\frac{7}{14}$  grs. K,  $476\frac{7}{14}$  grs. Cl; (d)  $386\frac{1}{10}$  grs. K,  $475\frac{25}{101}$  grs. O;  $138\frac{6}{101}$  grs. N; (e)  $448\frac{2}{3}$  grs. K,  $367\frac{7}{3}$  grs. O;  $183\frac{7}{3}$  grs. S; (f)  $286\frac{1}{3}$  grs. K,  $470\frac{0}{7}$  grs. O;  $235\frac{5}{17}$  grs. S;  $7\frac{6}{13}$  grs. H; (g)  $565\frac{5}{23}$  grs. K,  $347\frac{1}{23}$  grs. O,  $86\frac{2}{23}$  grs. C; (h) 390 grs. K, 480 grs. O, 120 grs. C, 10 grs. H; (i)  $286\frac{1}{3}$  grs. K,  $470\frac{0}{7}$  grs. O,  $227\frac{1}{7}$  grs. P,  $14\frac{1}{2}$  grs. H; (j)  $448\frac{8}{29}$  grs. K,  $367\frac{1}{8}$  grs. O,  $178\frac{1}{8}$  grs. P,  $5\frac{5}{7}$  grs. H; (k)  $551\frac{1}{3}$  grs. K,  $301\frac{1}{3}$  grs. O,  $146\frac{1}{3}$  grs. P.

129— $71\frac{3}{4}$  lbs. Ca;  $28\frac{1}{4}$  lbs. O.

130—71 lbs.

131—44 lbs.  $\text{CO}_2$  will be absorbed; 18 lbs.  $\text{H}_2\text{O}$  will be set free and evaporated; 100 lbs.  $\text{CaCO}_3$  will remain.

132— $1\frac{1}{2}$  lbs.

133—60 lbs. Mg; 40 lbs. O.

134— $1066\frac{2}{3}$  lb. O;  $933\frac{1}{3}$  lb. Si.

135—529.4 grains.

136—All the differences cannot be given here; but, from the proximate analysis of wheat grain the ultimate analyses deduced would be C, 389.4; O, 370.3; H, 54.6; N, 20.8; and of wheat straw C, 363.2; O, 383.7; H, 51.4; N, 3.4.

137—(a) 34795 tons; (b) 10534.8 tons; (c) 485.9 tons; (d) 27.5 tons; (e) 7.5 tons; (f) 91.7 lbs.; (g) 54 tons.

138—1.07 inches.

139—24.24 lbs.

140—7700 lbs. of  $\text{CO}_2$ ; 68 lbs. of  $\text{NH}_3$ ; 2232 lbs. of  $\text{H}_2\text{O}$ ; 6416.4 tons.

141—A little more than 18%.

142—92.4 lbs.

143—121.4 lbs.

144—Loam.

145—Sandy loam.

146—Loam.

147—Sand.

148—Strong clay.

149—91½ lbs. per cubic foot; 3996630 lbs. per acre, one foot deep.

150—80 lbs. ; 3484800 lbs.

151—277500 lbs

152—Organic matter, 194 tons; silica, 1296 tons; alumina, 114 tons; lime, 118 tons; magnesia, 17 tons; oxide of iron, 122 tons; oxide of manganese, 2 tons; potash, 4 tons; soda, 8 tons; chlorine, 4 tons; sulphuric acid, 4 tons; phosphoric acid, 9 tons; carbonic acid, 80 tons.

153—102½ loads.

154—\$550.

155—\$456.

156—14.

157—16.

158—473; 426; 4; 453.

159—605; 57; 55; 59.

160—35.

161—800 rods.

162—880 rods.

163—680 rods.

164—

	Depth.	4 ft.	3 ft. 6 in.	3 ft.	2 ft. 6 in.
As in 161 with collars		\$640	\$616·00	\$584·00	\$544·00
“ without “		\$600	\$576·00	\$544·00	\$504·00
“ 162 with “		\$704	\$677·60	\$642·40	\$598·40
“ “ without “		\$660	\$633·60	\$598·40	\$554·40
“ 163 with “		\$544	\$523·60	\$496·40	\$462·40
“ “ without “		\$510	\$489·60	\$462·40	\$428·40

165—\$4800.

166—\$1022.

167—91½ %.

168—2·21 %; \$99·20.

169—In the former case he will gain 5c per acre, in the latter he will lose 10c per acre by ploughing in buckwheat.

170—\$3·70.

171—\$1·48.

172—\$24·50.

173—\$42.

174—\$33·50.

175—\$37·50.

176—\$23·00.

177—\$31·40.

178—\$37·50.

179—\$79·00.

180—It was worth only \$42·25 a ton.



one foot

alumina,  
ron, 122  
, 8 tons;  
d, 9 tons;

181—\$71.10.

182—\$18.90.

183—\$1.26.

184—\$20.

185—One bushel of wheat, 26c.; barley, 17c.; oats, 12c.; rye, 21c.; maize, 20c.; peas, 40c.; potatoes, 5.3c.; carrots, 4.5c.; mangolds, 3.7c.; rutabagas, 5.2c.

186—One ton of wheat straw, \$2.12; barley straw, \$2.46; oat straw, \$2.83; rye straw, \$1.79; corn stalks, \$3.42; pea straw, \$4.79; timothy hay, \$6.75; red clover hay, \$9.52; green maize, 70c.; green rye, \$2.58; green oats, \$1.96.

187—Carrots, 7.9c.; mangolds, 6.7c.

188—Turnips, 10c.; carrots, 9.6c.; mangolds, 7.5c.

189—Turnips, 11.8c.; carrots, 11.7c.; mangolds, 9.7c.

2 ft. 6 in.  
\$544.00  
\$504.00  
\$598.40  
\$554.40  
\$462.40  
\$428.40

the latter